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METAL PROGRESS

SEPTEMBER · 1934

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All will mourn the untimely death of William H. Bassett, one of the first men to bring science into the brass industry. He was for years technical superintendent and metallurgical manager for American Brass Co., and a liberal contributor of his time, great talents and wide knowledge to the advancement of metallurgy.

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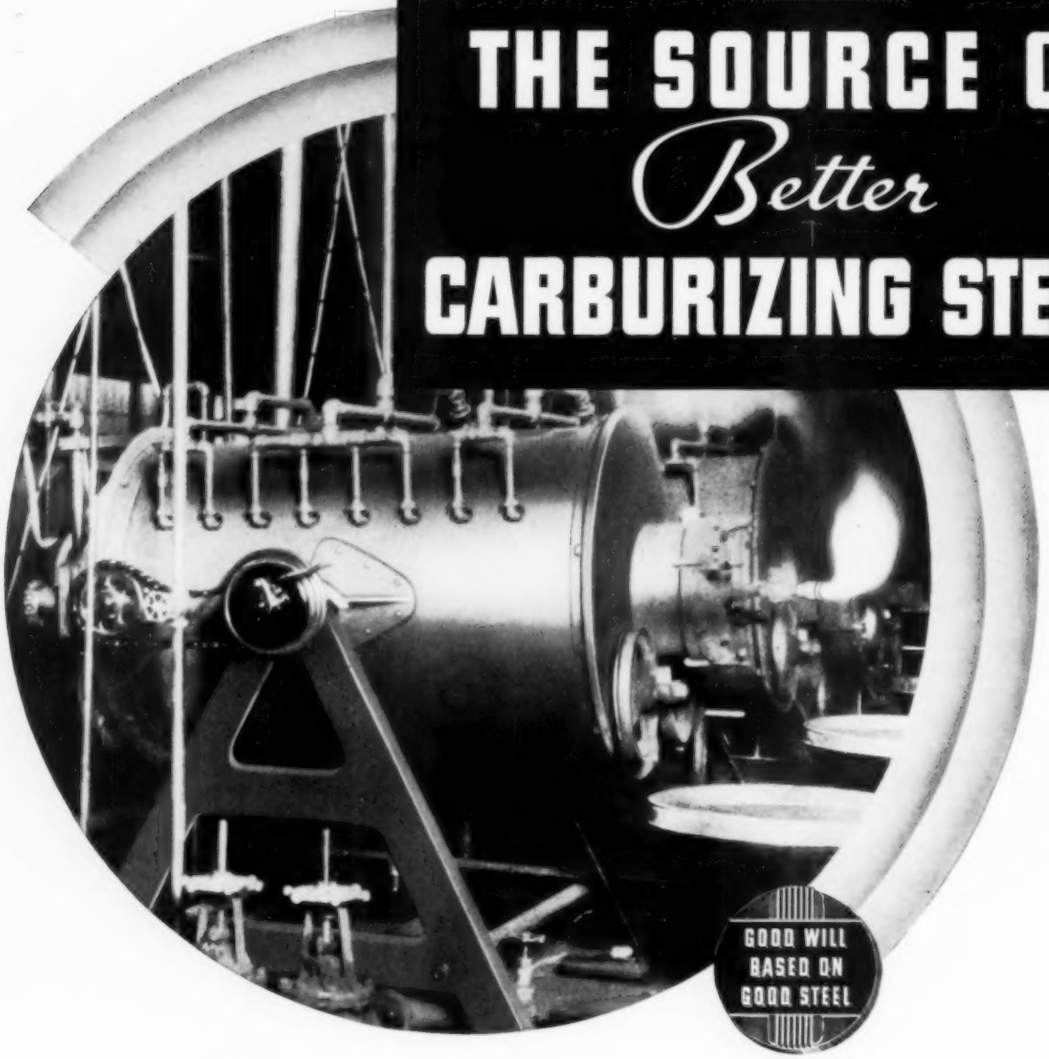

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Petroleum Refineries Consume Large Quantities of 5% Chromium Steel Tubing for Its Superior Corrosion and Heat Resistance. Photo taken in Whiting plant of Standard Oil Co. by Underwood & Underwood

STEELS WITH UP TO 7% .. CHROMIUM . . .

By S. M. Norwood
Union Carbide & Carbon Corp.
New York

CHROMIUM STEEL was the first alloy steel to be commercialized. It also was a distinctively American development, for Julius Baur established the Chrome Steel Works in Brooklyn in 1869, a plant which operated under that name for more than 50 years.

These early alloy steels were used for their unusual hardness, and their modern counterparts exist in the S.A.E. 5120 steel for case hardening purposes and the S.A.E. 52100 for roller and ball bearings. It is my present intention to review some developments of the last few years in chromium steels containing more alloy than the above mentioned, yet not enough to bring them into the true "stainless" class.

One of these was suggested after studies at Union Carbide & Carbon Research Laboratories wherein advantage is taken of three alloying elements, chromium, manganese, and silicon (hence its name "cromansil"). It was developed primarily to provide a material with higher physical properties than plain carbon steel in the as-rolled condition. The percentage of alloying elements is small and this, combined with the fact that heat treatment may be eliminated, keeps it out of the higher priced class of steels dependent upon heat treatment to bring out the advantages of the alloying elements. It generally contains 0.40 to 0.60% chromium, 1.10 to 1.30% manganese, and 0.60 to 0.80% silicon. Carbon content may be varied according to the physical properties desired.

Silicon contributes its well-known benefit in increasing the yield point without detrimental loss of machinability, which often results from other hardening elements. There is some increase in tensile strength due to silicon, but the manganese is much more important insofar as that is concerned. The combined benefits of silicon and manganese, widely recognized through the use of silicon-manganese steels for springs, is emphasized still more when chromium is added.

Thus, the cromansil steels, as rolled, have improved ductility as compared with the plain manganese steels with the same carbon content and the same ultimate strength. This benefit of chromium is even more pronounced in compositions having high ultimate strength.

Data on the physical properties have been given to readers of METAL PROGRESS by Richard Tull in the February, 1932, issue, and need not

be repeated. Suffice it to say that structural shapes having 65,000 psi. (lb. per sq.in.) yield, 99,000 psi. ultimate, 27% elongation in 2 in., 64% reduction of area in the as-rolled condition (Brinell 200 to 220) are particularly desirable for large structures where weight should be reduced without going out of range in cost.

Some information secured since Mr. Tull's article will now be noted:

Fatigue limit is high, being about 55% of the ultimate strength. Specimens tested in a Farmer testing machine did not fail after 10 million revolutions as follows: Staybolt analysis (0.05% C, 0.25% Cr, 1.12% Mn, 0.87% Si) normalized at 1790° F. did not fail at an alternating load of ±38,500 psi. The structural grade (0.32% C, 0.46% Cr, 1.07% Mn, 0.94% Si) was tested in two conditions. Normalized at 1790° F., it did not fail at ±50,000 psi.; oil quenched from 1700° F. and drawn at 1100° F., it did not fail at ±70,000 psi.

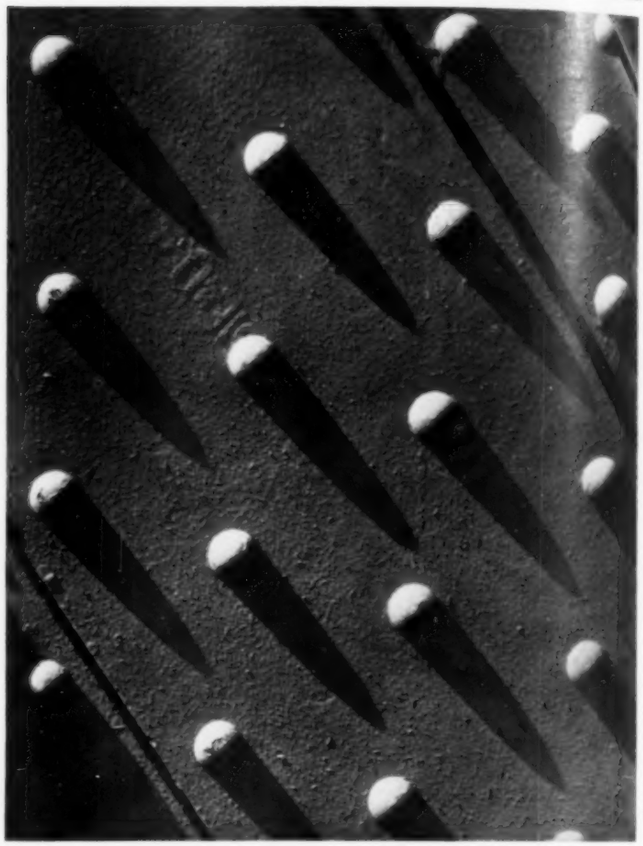
Low carbon ranges of cromansil steel have been found to retain their toughness at low temperatures to a remarkable degree. For example, one containing 0.06% carbon gave a Charpy impact value of 59 ft-lb. at room temperature, 51 ft-lb. at 0° F., 41 ft-lb. at —40° F., and 37 ft-lb. at —60° F. Low temperature impact is receiving much consideration at this time and the retention of the toughness by this steel is, in general, above the average for steels possessing equal tensile properties.

Coefficient of expansion is practically identical with plain carbon steel. Thermal conductivity is about one-quarter that of Armco iron and about 40% that of firebox steel.

In an oxidation test of nine weeks' exposure to 1500° F., cromansil lost only 78% as much weight as plain steel. This may be attributed to the high silicon content, but such steels are not generally recommended for resistance to high temperature oxidation, as this role is more aptly played by the higher chromium steels.

Creep values at high temperatures are favorable, as indicated by the following table comparing them with other well-known alloys. Stress noted is that required to produce 1% elongation in 10,000 hr. at 1000° F.

Steel	*Stress*
0.20% C cromansil	5750 psi.
0.26% C cromansil	6570
0.20% C	3900
0.45% C	4500
0.34% C, 3.46% Ni	5000
0.40% C, 1.30% Ni, 0.66% Cr	6000
0.40% C, 0.79% Cr, 0.57% V	6000



Cromansil Rivets and Structural Shapes Supply a Demand for High Strength Members Where Weight and Cost Must Be Saved. Photo by Henry Mayer

Fabrication qualities are also important, and tests on riveted joints have been conducted at Lehigh University and by A. E. Gibson, vice-president of Wellman Engineering Co., Cleveland. In these tests and in shop practice cromansil rivets have been found to be excellent for high strength plate and perhaps superior to any high strength rivet available at the present time. The medium manganese high strength rivet containing about 1.5% of manganese hardens very readily after the riveting operation and is difficult to chip, and is, of course, open to the objections found with any rivet material which hardens excessively when subjected to riveting treatment. The cromansil rivet does not harden to such an extent that it is difficult to chip unless the carbon content is too high; up to 0.20% has been found very satisfactory.

As to the other results of these fabrication tests, it will suffice to say that (1) all joints developed high strength; (2) the butt joints failed in tension of the plate at a section through the outer row of rivets, and the stress on the net section at failure was about 106,000 psi.; (3) the lap

joints failed by shearing of rivets at a stress in single shear of 67,000 psi. for the air hammer joint and 78,000 psi. for the hydraulic riveted joint; (4) no trouble was experienced at any stage of making these joints. The one conclusion to be drawn from the results of these tests is that perfectly satisfactory high strength riveted joints can be made without any difficulty with cromansil steel plate and rivets.

The above test pieces used low carbon rivets; since that time sufficient tests have been made employing approximately 0.20% carbon cromansil which indicate that even with this higher carbon content very good results can be obtained where still higher physical properties in the riveted joints are desired. Undriven rivets of such material test Rockwell B-84 and 64,000 psi. in double shear; after driving, the rivet is B-90 hard and has 112,000 psi. in double shear.

Plain Chromium Steels; 1 to 3%

There is a considerable amount of physical data available upon the forged and rolled steels containing between 1% and 3% chromium, as well as corrosion data, but I shall discuss only generalities at this time.

Steels of this type develop high tensile properties by simple heat treatments such as air cooling from suitable temperatures. Tempering will increase the ductility and in some cases improve the other physical properties. It is important to note that high impact values are obtained with these high tensile properties.

These chromium steels respond to air hardening in much the same manner that the high strength structural steels respond to a liquid quench; for the most part this is due to the chromium-carbon ratio. Air hardening of a 1% chromium steel is not outstanding until the carbon is in excess of 0.35%. However, as chromium rises above 3%, air hardening is appreciable with as little as 0.10% of carbon. These facts are well shown in the adjoining table of physical properties on this page. However, the 1% Cr steel with even 0.30% carbon is not appreciably harder (Rockwell test) in the normalized condition than when annealed.

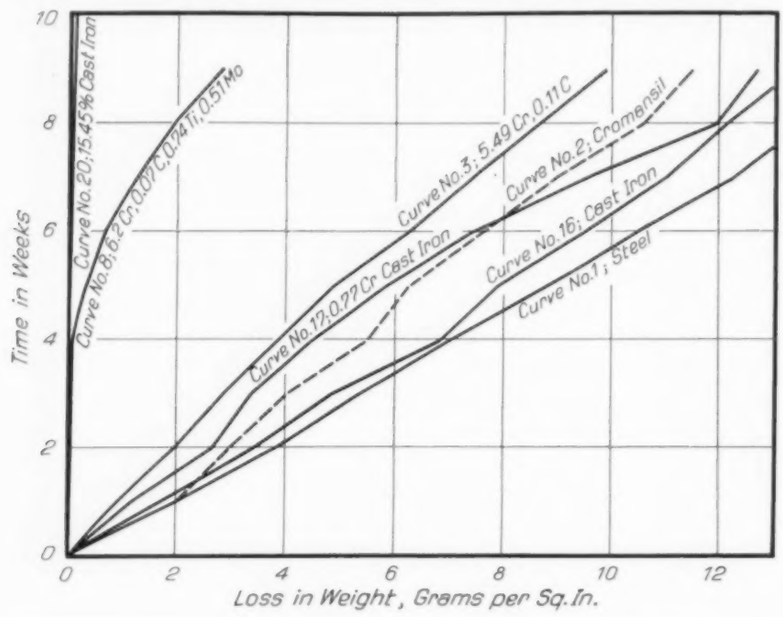
As the chromium content is increased above 3%, the resistance to corrosion is improved more than the physical properties, and the alloys containing upward of 4% are largely used where corrosion resistance is a factor. This statement is made on the basis of tests in aerated solutions of water, dilute HCl, dilute H_2SO_4 and NaCl solutions aerated with both air and H_2S. In general, the corrosion resistance increases as the chromium present in solid solution increases; of course, with a given chromium content the corrosion resistance increases as the carbon content decreases.

Chromium steels have a combination of toughness and hardness which makes them very suitable for wear resistant parts. In particular, the 3% grade is extremely well suited to such parts as rock crushing equipment and dipper and dredge teeth. Chromium imparts a unique depth hardening quality which simplifies heat treatment and insures good uniform properties throughout massive sections and throughout castings of greatly varying section. Considering the fact that chromium has the lowest cost of any of the better alloying elements used in steels, it is evident that through its use the metallurgist can often obtain the maximum in properties at the minimum of expense.

Above considerations indicate an impor-

Properties of Cr Steels; Air Hardened from 1625°F

Drawing Temperature	Yield Strength	Tensile Strength	Elongation in 2 in.	Reduction of Area	Izod Impact	Charpy Impact
1% Chromium, 0.10% Carbon						
Not drawn	44,410	60,000	41.5	75.4	88.2	62.9
1020°F.	44,050	59,190	42.5	76.0	86.6	59.6
Furnace cool	32,590	53,830	43.0	77.5	87.7	60.0
1% Chromium, 0.30% Carbon						
Not drawn	62,680	97,260	24.5	60.5	42.3	32.0
1020°F.	60,140	96,750	26.0	60.0	40.0	29.1
Furnace cool	43,910	81,800	28.0	48.9	39.6	19.0
3.15% Chromium, 0.11% Carbon						
Not drawn	60,570	102,380	19.0	49.1	29.6	24.8
1020°F.	78,400	112,900	18.0	51.6	34.8	26.8
Furnace cool	23,670	60,240	40.0	78.2	88.4	57.5
3.15% Chromium, 0.30% Carbon						
Not drawn	116,570	207,450	10.5	26.6	19.3	18.3
1020°F.	137,700	174,190	16.0	48.7	13.0	15.2
Furnace cool	37,290	87,470	30.0	65.6	12.9	28.4
5.25% Chromium, 0.10% Carbon						
Not drawn	108,860	181,420	15.5	53.2	23.3	18.5
1020°F.	128,850	169,480	16.5	57.4	8.1	19.1
Furnace cool	27,300	66,030	37.5	75.6	76.8	47.0
5.25% Chromium, 0.30% Carbon						
Not drawn	117,260	221,830	13.5	31.7	17.9	15.4
1020°F.	144,300	195,950	14.5	47.2	13.3	14.5
Furnace cool	33,420	78,990	33.5	75.6	79.9	79.4
7.25% Chromium, 0.10% Carbon						
Not drawn	111,640	192,040	13.0	42.7	20.2	21.0
1020°F.	129,890	180,330	16.0	54.3	19.4	19.3
Furnace cool	28,980	67,870	37.0	77.8	96.5	66.6
7.25% Chromium, 0.30% Carbon						
Not drawn	122,780	233,160	12.5	35.4	16.6	9.6
1020°F.	144,840	195,300	13.0	41.6	15.0	13.0
Furnace cool	37,870	84,650	33.5	75.3	90.4	80.3


Time in Weeks
Loss in Weight, Grams per Sq. In.
Curve No. 20; 15.45% Cast Iron
Curve No. 8; 6.2 Cr, 0.07 C, 0.74 Ti, 0.51 Mo
Curve No. 3; 5.49 Cr, 0.11 C
Curve No. 2; Cromansil
Curve No. 17; 0.77 Cr Cast Iron
Curve No. 16; Cast Iron
Curve No. 1; Steel

Cumulative Loss by Oxidation of Small Cylinders Heated in Air at 1500° F. for Long Periods of Time. Proper amounts of titanium greatly increase the scale resistance — compare curves 8 and 3

tant use of 3% Cr, 0.30% C steels for main line railroad rails, as described fully by Prof. Waterhouse in METAL PROGRESS in April. Service records for the last five years have been most satisfactory and substantiate anticipations based on laboratory and mill tests. They have a combination of strength, toughness and wear resistance that is unique, so far as we know.

4 to 6% Chromium Steel

A great deal of interest has been developed in the 4 to 6% chromium steels in the last few years. It may be well to know a little bit of the history back of their development.

Several years ago one of the large oil companies wished to secure steels with a minimum investment which would resist corrosion considerably better than plain carbon steel (particularly in oil refineries) — something intermediate in corrosion resistance between plain carbon steels and the stainless steels. Upon being consulted, our Laboratories furnished a series of steels containing between 1 and 20% chromium, varying by approximately 1% steps. These were then tested by the oil company and 4 to 6% was decided upon as giving suitable properties for the purpose intended. It was not long before seamless tubes of this steel were in fairly large tonnage production.

As mentioned before, the steels containing 4% of chromium are air hardening with as little as 0.10% carbon, and therefore considerable technique is necessary in the production of large tonnages of these steels to avoid failure from thermal stresses.

It is now general knowledge that all such seamless tubes of this composition should be furnished in the dead annealed condition and that the sensitivity to temper embrittlement is more pronounced if the rolled material has not had an anneal at a temperature above 1450° F.

A prominent engineer described extensive service experience with these tubes at one of the refineries before the meeting of the A.S.T.M. in June. After several campaigns at 1000 to 1200° F. the tubes acquire a certain brittleness at winter temperatures (16 ft-lb. for V-notch Charpy specimens as compared with 50 for an unused tube), but the impact resistance is entirely recovered at boiling water temperatures. It is the practice, therefore, to fire each unit of

Effect of 0.80% Titanium on 4.75% Cr, 0.12% C Steel

Heat Treatment	Titanium	Elastic Limit	Tensile Strength	Elongation	Reduction	Brinell
As rolled	none	60,000	186,000	12.5	30.2	375
	0.80%	35,000	67,500	27.0	51.4	137
1600°F. for 1 hr., air cooled [A]	none	60,000	182,000	11.0	26.5	367
	0.80%	20,000	60,000	31.0	59.1	126
1600°F. for 1 hr., furnace cooled [B]	none	25,000	78,000	31.5	72.9	141
	0.80%	19,000	60,000	34.0	61.4	124
[A], then air cooled from 1425°F.	none	54,000	87,000	27.5	74.5	178
	0.80%	20,000	61,000	35.2	65.6	123
[B], then furnace cooled from 1425°F.	none	21,000	66,000	35.5	75.2	137
	0.80%	18,000	60,500	38.7	71.9	123

refinery equipment containing 5% chromium tubes with steam after each shut-down for cleaning, and make a pressure test to discover any leakage from an occasional cracked tube before running in the oil.

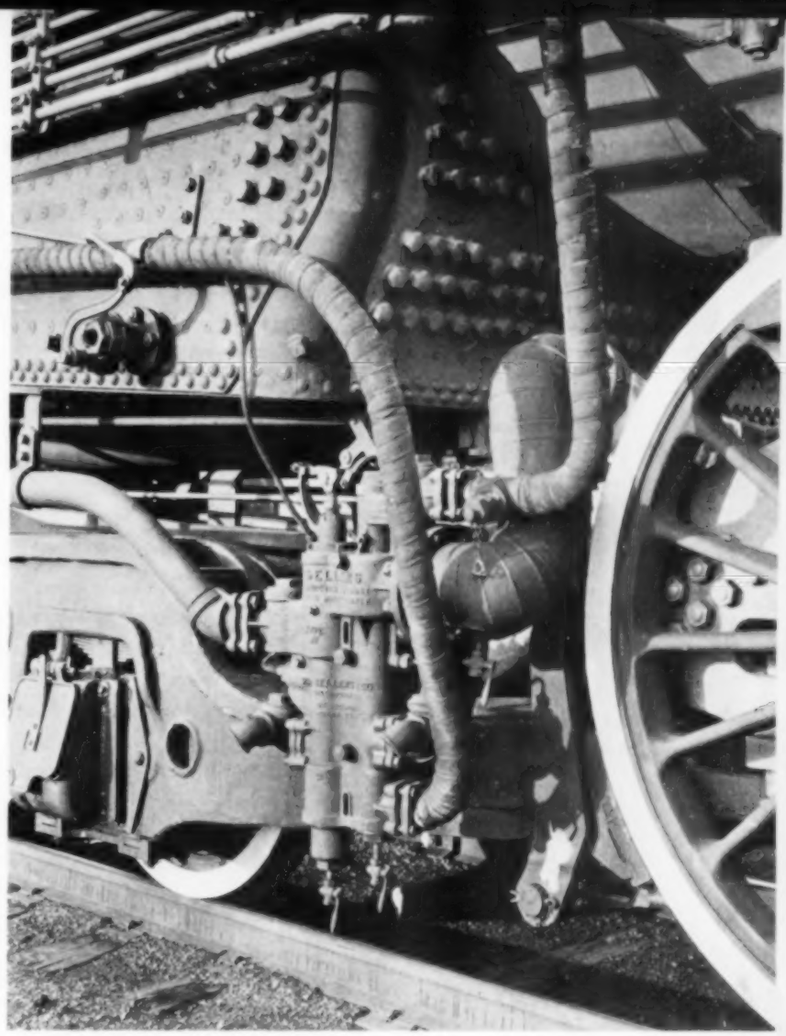
A de-coking method has been in the process of development for the past year or so which removes the deposited coke and carbon with an "oxygen lance." This method avoids the mechanical shocks, so detrimental to the life of the tube, which are encountered when the present type of knocker is used for de-coking the tubes.

At first the material was furnished without the addition of other alloying elements; a little later additions were made to the extent of approximately ½% molybdenum or 1% tungsten. There are still many schools of thought as to the advantages of the different alloying additions. There is apparently an improvement in creep values with the alloying additions, and other advantages are too controversial to discuss here.

The 5% chromium alloys, with or without molybdenum or tungsten, are reported to give a life of 3 to 20 times that obtained with ordinary carbon steel. It is known that the resistance to oxidation at elevated temperatures increases as the carbon content of these steels decreases — in other words, the amount of chromium in solid solution is really the measuring stick for resistance to corrosion or high temperature oxidation. It may be for this reason that the addition of molybdenum or tungsten in small amounts tends to increase the resistance to corrosion, as both are carbide-forming elements, thus interfering with the free formation of chromium carbide, and retaining chromium in the solid solution.

There is an apparent discrepancy in this, as certain tests have indicated that this class of steel with the addition of molybdenum or tungsten has shown a lower resistance to *oxidation* at elevated temperatures, yet at the same time they have shown an increase in *corrosion* resistance. It is the writer's opinion that such discrepancies would disappear if comparisons were made on materials which have received the same heat treatment and which contained the same percentages of chromium and carbon. It might also be mentioned here that silicon likewise plays an important part, particularly as regards resistance to oxidation at elevated temperatures, and for that reason the silicon content should also be considered when comparisons are made.

A very interesting development from our laboratories has to do with the addition of titanium. Titanium eliminates the air hardening



Medium Carbon Steel With 3% Chromium Has That Unique Combination of Strength, Toughness, and Wear Resistance Demanded by Rails and Tires. Photo by Hoedt for Wm. Sellers

characteristics of these alloys when present in the proportions of 4 to 6 times the carbon content. It is to be remembered that the ability to produce increased physical properties by heat treatment is also eliminated. Figures in the table on page 20, which compare the physical characteristics of a straight 4½% chromium steel with one containing titanium, came from one of the large steel companies.

Elimination of air hardening is important in the production of rolled materials, as it avoids the necessity for lengthy anneals to put the alloy in workable or machinable form. Titanium-bearing material "as rolled" will not be much harder than Brinell 150, and it is therefore capable of being straightened, machined, or having other forming work carried out. If it is desired to relieve all thermal stresses, it can be annealed or heated to about 1600° F. for 15 to 20 min.

One of the very interesting features which was also brought out in our development was the improvement in this *(Continued on page 56)*

HEAT TREATMENT FOR GRAIN SIZE IN CAST STEEL

By C. E. Sims
Asst. Research Director
American Steel Foundries
East Chicago, Ind.

MUCH attention has been given to the grain size of steel "as cast," although it is seldom used in this condition. The influences which produce the various structures (such as the appearance or absence of Widmanstätten plates in steels of almost identical composition) are not thoroughly understood. For the purposes of the present discussion it may be pointed out that grain size "as cast" has only an indirect influence on the response of cast steel to subsequent heat treatments, and that influence is principally because of its relation to segregation.

Segregation is the non-uniform distribution of chemical elements in the solid metal. The general causes of this segregation are understood with some definiteness; as is well known, it is a phenomenon inseparable with the process of gradual freezing of solid solution alloys, such as steel. It will now be shown that a fine, uniform grain can be induced in steel castings only after a preliminary heat treatment whose main objective is to obtain as great a degree of homogeneity as possible in a reasonable time. Some grain refinement may be achieved during this preliminary treatment, but where a fine, uniform grain is desired, a second or third heat treatment is usually required.

For the purpose of illustrating the principles of heat treatment, an intermediate manganese steel containing 0.30 to 0.40% carbon and 1.25 to 1.50% manganese will be used. This composition is well suited to the purpose because it is a very "normal" steel, grain growth is readily accomplished, and the grains are well outlined. In fact, it is a steel in which fine grains are difficult to obtain.

The raw or unannealed structure of this steel as cast in a 1-in. section is shown at 100 diameters in the first group of micros. If such a steel be heated slightly above the upper critical temperature (say to 1550° F.) for a moderate time, as an hour, and allowed to cool in air, a profound change in grain structure will take place as shown; there is a conglomerate mixture of grain sizes, some very large, others quite small. Recrystallization has taken place with the initial formation of myriads of small grains. Some favored few grew very rapidly; others remained almost unchanged in size. If the time of heating should be doubled, say to 2 hr., it would be found that the large grains had become much larger, yet many of the small ones would remain. The irregularity in size is apparently due to dendritic segregation which has not been satisfactorily

eliminated by diffusion during the heat treatment.

The significance of such a grain structure is that experience has told us that such a steel will not have good physical properties, and it will still have a "raw" fracture. The normalizing temperature is too low; it will take an impracticably long time to get proper diffusion with the accompanying uniformity of grain size. Even then the grain size will be too large; the small grains do not grow, but they are finally absorbed by the larger ones.

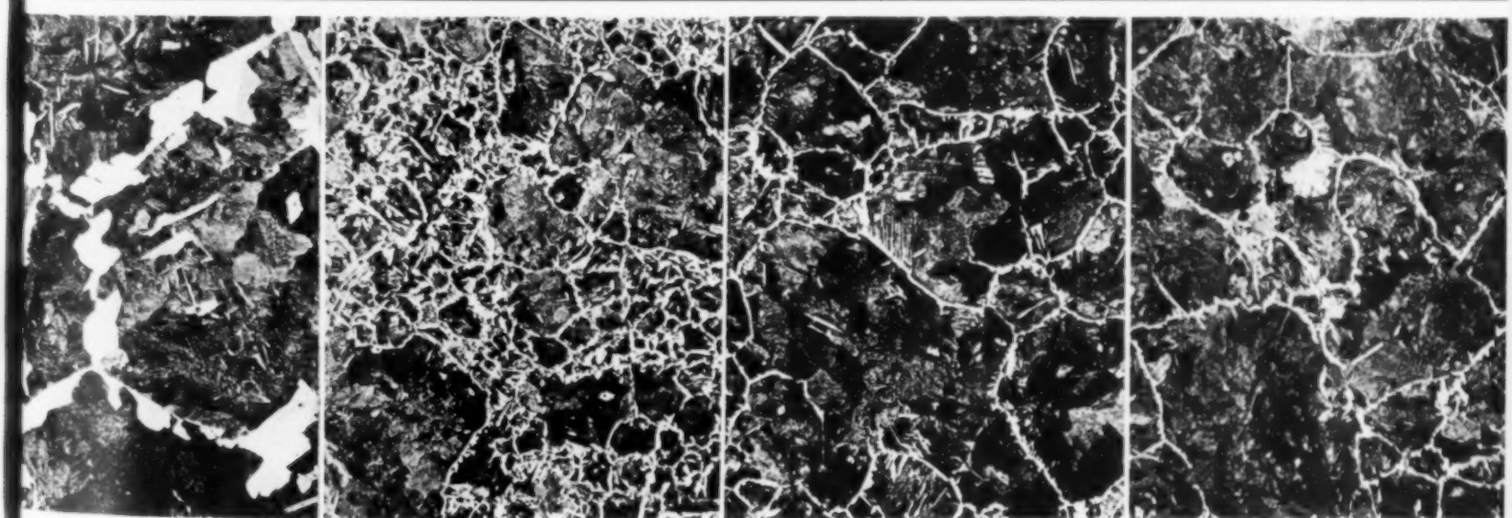
Now if the normalizing temperature is stepped 100° higher to 1650° F. and a piece of the same steel is held a short time (say, 15 min.), a very similar structure is obtained. This also is underheated, or "under-annealed" — to use shop terminology. But if the piece is held at that temperature for 1 hr., it is found that the very small grains are almost completely eliminated; a much greater degree of uniformity is achieved, as shown in the third micro in the first group. This steel will not break with a "raw" fracture, and although the grain size is too large to give the best properties, the first hurdle in heat treatment has been passed. One hour was the minimum time in which this result could be achieved; of course, a considerably longer time would be required in practice.

If another 100° is added, the same result is obtained in half the time. The last view in the group below gives the results of such a 30-min. treatment at 1750° F.

The above conditions refer to metal as cast in 1-in. sections. The first figure in the group on page 24 shows conditions at 25 diameters of this same steel in the "as cast" condition in the center of a 6-in. section. The characteristics are similar to the 1-in. section, the principal difference being that everything is on a larger scale. A 1-in. cube cut from the center of such a section and heated to 1650° F. for 1 hr. gave a mixture of coarse and fine grains as shown; it will be recalled that 1 hr. at 1650° F. sufficed to eliminate the very small grains in a piece cast as a 1-in. section, but for thick sections, 1 hr. is obviously not long enough.

If the center of a 6-in. cube, cast and treated as a 6-in. section, is examined after being heated at 1650° F. for 1 hr., we find good confirmation of this observation. Such a structure is shown at top right of the group on page 24. The slower cooling has caused much more ferrite to be separated, some in Widmanstätten plates. The eye of the experienced metallographist will readily detect evidence of "under annealing" (underheating) in these vestiges of the raw structure. (It is true, of course, that Widmanstätten plates are found in "over-annealed" or overheated steel, but there is a structural difference that can be recognized with practice.)

Going back to the 1-in. cube cut from the 6-in. section, it was found necessary to heat for 6 hr. at 1650° F. to break up the cast structure completely, and secure a structure almost precisely a duplicate of that obtained in the 1-in. section in



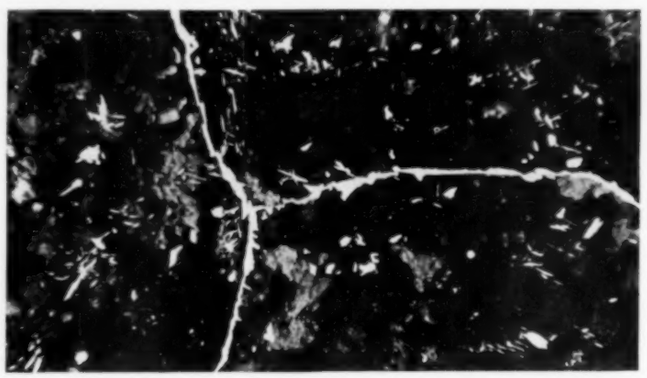
nnealed or raw structure | Air cooled after 1 hr. at 1550° F. | Air cooled after 1 hr. at 1650° F. | Air cooled after 30 min. at 1750° F

Effect of Preliminary Heat Treatment of Medium Manganese Steel Casting. Cast and Heat Treated as 1-In. Section. All magnified 100 diameters

1 hr. However, the center of the 6-in. section, treated for 6 hr., is as shown in the lower right figure below; here again, the slower cooling has caused a greater separation of ferrite, but no trace of the cast structure remains, and the average grain size is seen to be about the same as in the piece treated for the same time and temperature as a 1-in. section.

At 1550° F. it took approximately 12 hr. to bring about this same result; at 1750° F. it was accomplished in 3 hr.

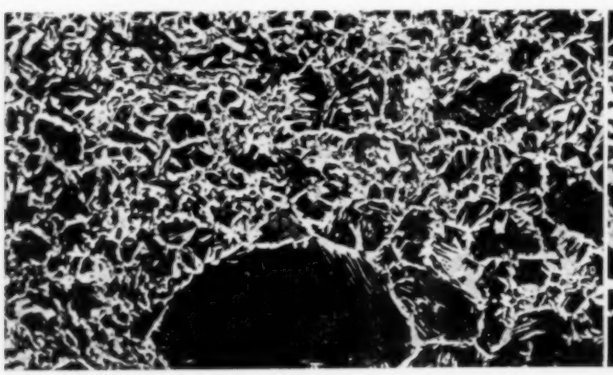
This brings us to two interesting conclusions. The first concerns the relation of grain growth and diffusion to temperature: Starting from a point definitely above the upper critical temperature (say, 1550° F.), each 100° increase in temperature seems to double the initial rate of grain growth and diffusion; that is to say, the time necessary to bring about a certain minimum effect is cut in half. Of course, this relation does not hold for prolonged periods, for diffusion slows up as uniformity is approached. It is also characteristic of grain growth at any given temperature that the rate is rapid at first and then slows down to virtual cessation; the higher the temperature, the larger the final average size. If after grain growth has practically ceased, the temperature be raised, grain growth



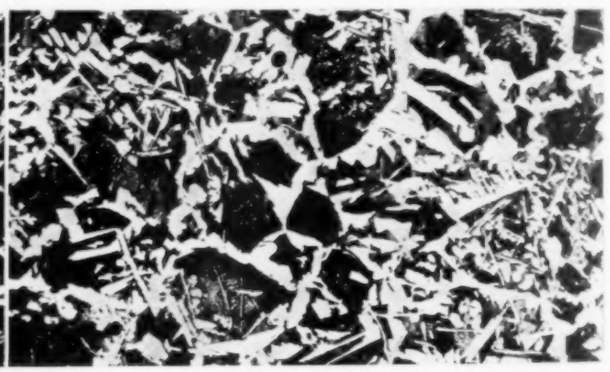
Raw Structure of Medium Manganese Casting at Center of a 6-In. Section. Magnified 25 diameters

Structures Below Are at 100X of 1-In. Cube Cut From Center

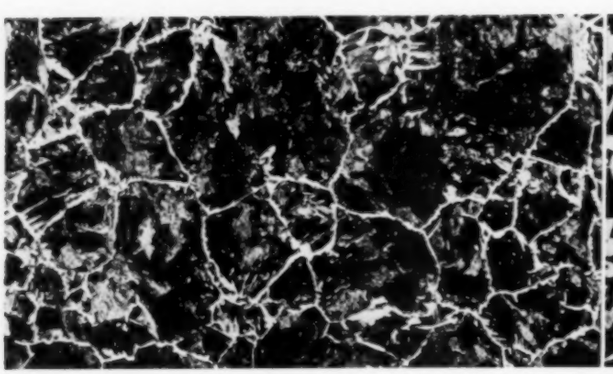
Structures Below Are at 100X of the Center of 6-In. Cube



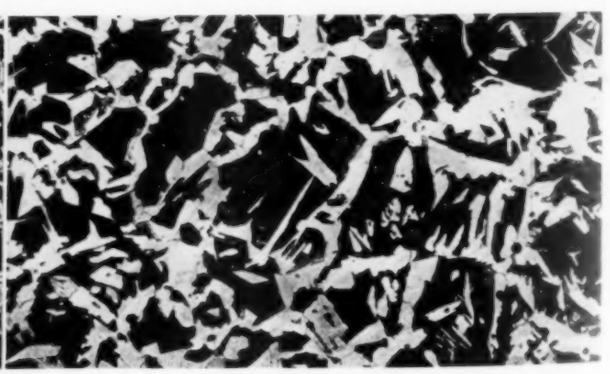
Air cooled after 1 hr. at 1650° F.



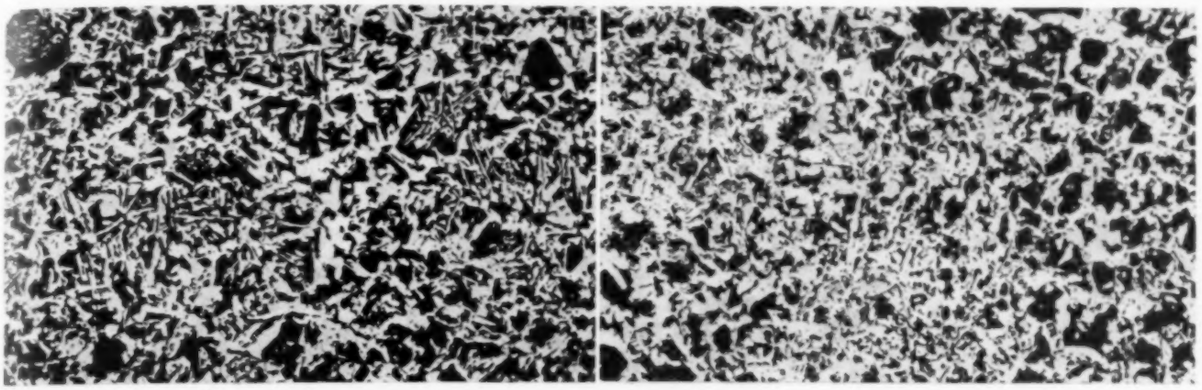
Air cooled after 1 hr. at 1650° F.



Air cooled after 6 hr. at 1650° F.



Air cooled after 6 hr. at 1650° F.



At Left Is Acicular Structure in Double Normalized Steel Due to Insufficient Heating During the First Normalizing Treatment; at Right Is the Properly Normalized Center of 9-In. Casting. Both magnified 100 diameters

will again start at favored places but will taper off at a larger size.

The other conclusion is in regard to the relation between size of section as cast and the time required for diffusion and grain growth to a uniform size. The greater section causes slower solidification in the mold, resulting in a greater degree of dendritic segregation. This greater segregation requires a longer time for diffusion and this in turn retards the grain growth. For this particular steel treated at 1650° F., the time in hours required for the minimum desired result is proportional to the section thickness in inches as follows: A 1-in. section, 1 hr.; a 6-in. section, 6 hr.; and a 9-in. section, 9 hr. Somewhere above 9 in., this proportion ceases to hold.

Influence of Previous Structure

After homogeneity (lack of segregation) has been reasonably well achieved by a proper anneal, it will be assumed that the second heat treatment has for its primary purpose the acquisition of a uniformly fine grain. It is obviously difficult to accomplish this during the first treatment. However, if the first treatment (diffusion) has been properly carried out, it then becomes a matter of recrystallization to get a fine grain, that is, to form as many crystals as possible and prevent the growth of some at the expense of others.

The general principles of this procedure are familiar to metallurgists and need not be detailed at this time. In brief, if grain growth is a function of time and temperature, it behooves one to keep the temperature down and the time short. There are, of course, practical limitations in the shop due to cost and danger to furnace, and a workable margin must be allowed.

Just as the grain size after the first treatment is influenced by the cast structure, so is the grain size after any later treatment influenced by the previous condition — but to a far less important degree. When a piece of steel has been underheated in the first treatment, a second treatment, which would be correct if it followed a proper first anneal, will produce a peculiar acicular structure somewhat resembling Widmanstätten plates but in a different pattern. Such a structure is shown in the left hand view of the pair on this page. On the other hand, if the steel has been overheated on the first treatment with the production of excessively large grains, the second treatment will not be able to give proper grain refinement.

The other micro in this pair shows what can be accomplished by proper treatment in the center of a 9-in. section of this steel.

Influence of Composition

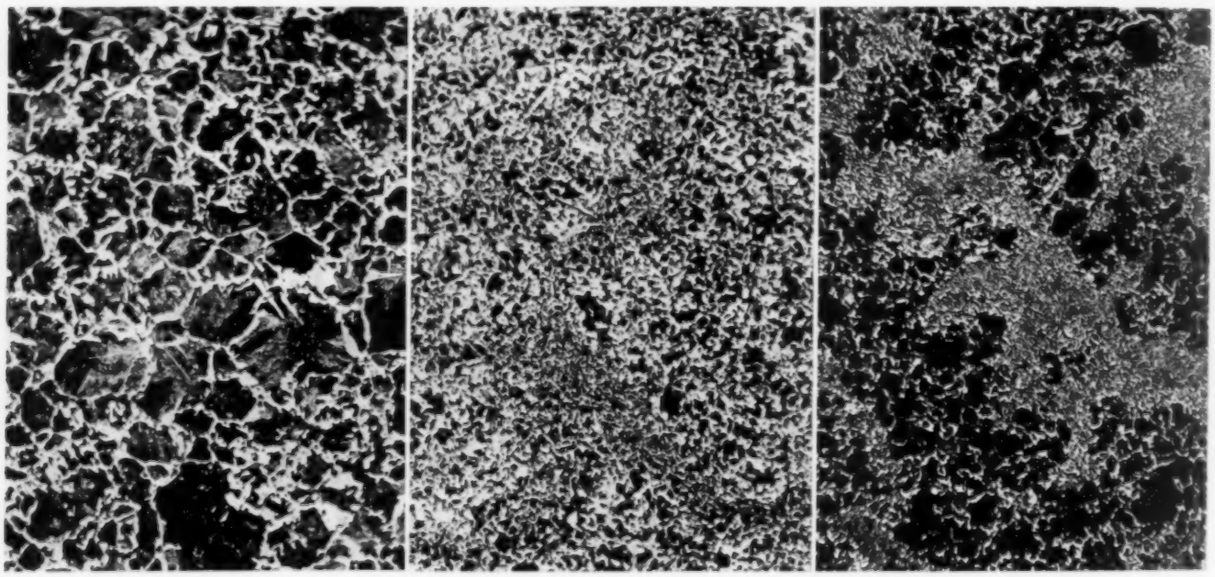
In discussing the influence of heat treatment so far, only one type of steel has been dealt with. This was to avoid confusion. But chemical composition itself can exert a strong influence on the grain size.

Carbon has but little effect, even through a considerable range. Probably the most effective element is vanadium, which is quite remarkable in its grain refining tendencies, as shown in the

group of three on this page. Of course, vanadium does not prevent grain growth, but it does act as a strong inhibitor. Just how vanadium accomplishes its effect has never been fully explained. Some suppose it to exist in the steel as an oxide in submicroscopic dispersion. In this form it could act to aid recrystallization by forming innumerable nuclei; with so many crystals formed, the struggle for existence would be keen enough to prevent a favored few from growing at the expense of the rest. Again, it might act merely as a mechanical barrier to grain growth, in much

Alloys Displace the Critical

Alloys cause steel to be sluggish at the allotropic change, and therefore tend to produce super-heating or super-cooling, as the case may be. It is a well-known law of physical chemistry that when crystallization occurs after supercooling it takes place more suddenly and with the formation of many very small crystals, as compared to fewer and larger crystals in the absence of super-cooling. The grain refinement caused by an alloy will be very nearly proportional to



At Left and Center Are Medium Manganese Steels of Same Composition (Except 0.1% Vanadium in Center Sample) and Same Casting and Heat Treating Histories. The effect of vanadium is unmistakable. Magnified 100 diameters

Right View Shows Coarse and Fine Grains in One Specimen, Due to Segregation of Manganese Near Boundaries of Primary Crystals. High manganese regions are fine-grained

the same manner as incorporated thorium oxide prevents grain growth in tungsten electric light filaments.

Aluminum acts in a similar manner but with less potency. It forms some visible refractory inclusions, but there may also be others of submicroscopic size.

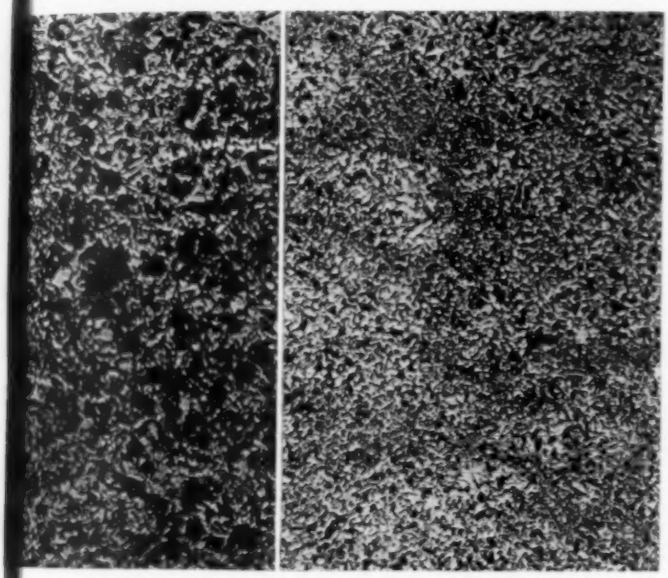
Alloying elements such as manganese, chromium, nickel, and molybdenum can also greatly influence grain size; in general, they tend toward grain refinement. Molybdenum is notable in this respect. It is probable that they exert their influence, indirectly, through their effect on the critical temperatures.

the elevation of the allotropic transformation above the true critical temperature of the steel when it is heated.

It seems also to be true that the presence of an alloying element interferes in some way with actual grain growth; and alloy steels will often stand a higher temperature than carbon steels without excessive grain growth.

An interesting illustration of the effect of alloy content on grain size is shown in the above group of micros. It was seen in some of the earlier illustrations that ordinary medium manganese steel has a marked tendency to large grain growth, it being a very normal steel. During the

solidification of a steel, manganese, in common with any other dissolved constituent, is subject to dendritic segregation. It is lowest in the centers and reaches its maximum richness near the boundaries of the primary crystals. If for any reason, such as being too plentiful, it is not redistributed by diffusion, it will give a mottled appearance to the microstructure, as shown. The areas rich in manganese are fine-grained and sorbitic, while those poor in manganese are larger grained and pearlitic. With a trifle faster rate of cooling, these fine-grained areas would be martensitic. With either very slow cooling or quenching from above the critical temperature, the mottled structure disappears.



Micros Showing Effect of Grain Size on Impact Toughness. Samples from same casting, one improperly heat treated to coarse grain with Izod impact of 18.5 ft-lb.; the other fine-grained with Izod of 48.0

As to the relation of grain size to the quenching of cast steel, it can be said that the same laws apply as in the case of other forms of steel. E. C. Bain in *Transactions*, A.S.S.T., Vol. 20, p. 385, has shown in the Campbell Memorial Lecture "Factors Affecting the Inherent Hardenability of Steel" that hardenability is a function of austenitic grain size, other things being equal. The larger grains give greater hardness and deeper penetration of the hardening effect. His address is worthy of study by all foundrymen.

Grain Size Vs. Physical Properties

Throughout this discussion it has been implied that a uniformly fine-grained steel is greatly to be desired. In general, this is true, for the very good reason that fine grains seem to be inextricably tied up with serviceability. Impact or shock resistance, the ability to take and absorb punishment, the ability to withstand temporary overloads — in short, the intestinal fortitude of a steel is greater with finer grain size.

Grain size may vary considerably without greatly affecting the static properties of a steel as revealed by the standard tensile test. This has led many to assume that close control of heat treatment is not important. The impact value, on the other hand, is greatly affected, and seems to be a far more sensitive test of the heat treatment of a casting than the tensile test.

An example of this is given in the table. This lists the properties of two samples of steel from the same heat of a medium manganese-vanadium steel. The only difference between these two samples is that one was given the correct heat treatment while the other received a wrong one. It will be noted that there is almost a duplication of strength and ductility, but that the Izod value of one is only 40% of the other. The left hand figure of the final pair shows the structure with the low impact strength; this can be regarded as relatively coarse-grained. The fineness of grain of 131-3 with the higher impact shown at the right, is in striking contrast, and one is forced to believe that the grain size itself is responsible for the difference in toughness (impact).

	Bar 131-2	*Bar 131-3*
Yield point	63,060	66,210
Ultimate strength	98,240	101,400
Elongation	27.0	27.5
Reduction of area	55.7	57.5
Izod impact	18.5	48.0

It would not be safe, however, to generalize and say that fine grain size is always desirable. Large grains are easier to machine, for instance. In uses where high temperature strength is needed, the large-grained casting is superior, other things being equal. Spring and Kanter have shown that even the raw steel sometimes has better high temperature strength than the same steel annealed or quenched. See their paper entitled "Some Long-Time Tension Tests at Elevated Temperatures," given before the A.S.T.M. in 1930.

PIONEERING METALLURGY IN DETROIT

William Park Woodside

("Bill" to a legion of friends)

Journeyman blacksmith and tool dresser
Steel salesman and pioneer serviceman
Founder, Steel Treating Research Society
Manager of methods and standards for Studebaker Corp.
President, Park Chemical Co.
Vice-President, Climax Molybdenum Co.
Director, American Society for Metals

Photo by Redman, Detroit

By C. N. Dawe
Manager, Automotive Division
Vanadium Corp. of America
Detroit

AUTOMOTIVE development in the 25 years' existence of the General Motors Corp. is so filled with bitter struggles and most laughable incidents that volumes could be written to cover the story. This is especially true of automotive engineering, culminating in designs which now give us an automobile of great speed, comfort, and quietness. However, how many know of the important part played by metallurgy in making possible this automobile, which runs for 50,000 to 100,000 miles under the most trying conditions of rough handling and speed without the failure of a part?

Do you know that the first laboratories for the microscopic study and control of steel and its heat treatment were put under way for General Motors in 1911 by Carl Zimmerschied, later president of Chevrolet, and at the old E.M.F. Co., by Carl Wise, now chief engineer of Pierce Arrow?

Do you know that many of the men, now big in the industry, laughed at us for looking at steel through a glass in that day?

Do you know that photomikes of steel, which showed the grain structure, were laughed at as looking like the "picture of a cookie"?

Do you know that steels put into the early automobile were not heat treated?

Do you know that Bill Woodside knows more about the steel problems which arose in the early days of the automobile than any other man in the industry?

Do you know that when Woodside told Bill Little, of the old Buick company, that he had heat treated a set of steering knuckles and arms to put in his car, Little said. "Nothing doing! I don't want any tempered steel in my car; I've seen enough tempered tools bust!" But Harry Bassett "took a chance" and put them on his new grey roadster?

Do you know that the heat treatment finally given to case hardened transmission gears, which prevented the teeth from snapping out, was discovered entirely by accident, and not developed by the new technical man, the Metallurgist, who had come into the field? (A gear found in a furnace heated for tools to above 1500° F., was cooled in oil and this was the only one in a lot quenched from around 1400° F. which was tough.)

Do you know that the Cadillac four-cylinder car was the first G.M.C. car to use alloy steel, and this was put into the transmission gears and pinion? Do you know that because of this, Walter Phipps was dubbed "one of the greatest metallurgists of the day"?

Do you know that there were only two different types of alloy steel used in early automobiles — and now there are more than 40?

Do you know that the rear axles of some of the early cars were so noisy when taken off the line that ground cork was thrown into the grease in the housing to quiet them down?

Do you know that broken axle shafts, piled room-high, bushel baskets full of broken gears and bearings, all from the field, were a common occurrence in the early days — and today such types of failures are rare?

Do you know that the automotive industry is responsible for the development of our great alloy steel mills, and that Fred Griffiths and his organization at the old Central Alloy Steel Co. in Massillon were outstanding in this development, and that Dr. Sargent and the late E. L. French (both of Crucible Steel Co.) are names we can't forget?

Do you know that the present great American Society for Metals is descended from a small gathering of heat treating foremen from the automobile plants of Detroit, who met to discuss their problems over a glass of beer, and H. J. Lawson, of the old Cadillac plant, was the first president of this local group, and its name was the Steel Treating Research Society?

* * *

EDITOR'S NOTE: These reminiscences of the early automotive industry were written for a special edition of *Automotive Industries* commemorating the silver anniversary of General Motors. They are well worthy of reproduction in METAL PROGRESS, despite its rule against reprinted material!

Do you know that "Bunny" Dawe delivered the first formal paper to be read before the Society, and it was entitled, "Why Camshafts Crack During the Grinding Operation"?

MODERN WELDS AND METALS .. FOR A HEATER

By F. C. Woodside
Air Conditioning Dept.
General Electric Co.
Schenectady, N. Y.

AN air-conditioning system for properly controlling indoor temperature, humidity, air movement, and air purity is a distinct advance in the art of providing ideal living conditions. Those who have recently experienced relief from torrid humidity by entering a properly air-cooled office, restaurant, movie, or railroad train find it difficult to refrain from becoming over-enthusiastic over the future possibilities of this new equipment.

In either a winter or a year-round system the modern heating unit acts as the heart of the installation and, in addition, provides an adequate supply of domestic hot water at all times, winter and summer. Advanced design and careful manufacturing from the best available specialized materials are foremost among the factors which make the ownership of such an appliance a constant source of delight and enable it to eliminate a long-established source of dirt, care and trouble in the household, besides giving unusual returns in comfort and health.

The editor has invited a description of the new G.E. oil furnace as an example of modern design and construction, where each part is based on the relation of that part to the complete device. These integral parts consist primarily of a boiler, compressor, burner head, control, insulation, and jacket. No attempt has been made to make these parts interchangeable with similar devices on other systems or to make them suitable for attachment to existing boilers or heating installations, for early considerations in the design of this furnace disclosed that a uniformly high efficiency could be obtained only by coordinating all parts to form a single unit.

Functions of Units

Materials for each part are selected to give best results, including long life and resistance to corrosion from heated air, combustion products, fuel oil, or hot water. The nozzle tip of the burner, for instance, is monel metal; the heater coil is copper; the rod for expansion relief door, the sight-door shutter, water-circulator shaft, and certain parts of the jacket are stainless steel. Magnetic and electrical alloys are installed in motors and control equipment. Besides these, there are many other specifications of more common steel and iron employed, and the selection of each one, as well as the specification of the heat treatment and finish for the individual parts, is an important step in the design procedure.

A brief description of the functions performed by the major parts of the furnace will help to explain the choice of materials and will bring out some of the reasons for their particular design. The schematic vertical section shown in the cut below will be helpful to the reader.

The compressor unit, which is mounted at the top, draws fuel oil from the storage tank, supplies atomizing air and fuel oil to the burner head under about 15 psi. pressure, and provides both primary and secondary combustion air. As indicated on the diagram, a single vertical shaft carries the rotary oil-and-air pump (below), the motor rotor (midway), and the multi-vane blower (above). The oil-and-air pump is arranged to pump oil during a part of each revolution and air during the remainder, discharging both into a sump from which they are led separately to the burner head.

Combustion air is taken from the space beneath the top cover, into which it enters through louvres in the air ducts at each side of the furnace. This scheme provides sufficient cooling for the motor and controls, prevents transmission of noise, and insures that all air leaks are inward so that petroleum odors cannot reach the living quarters.

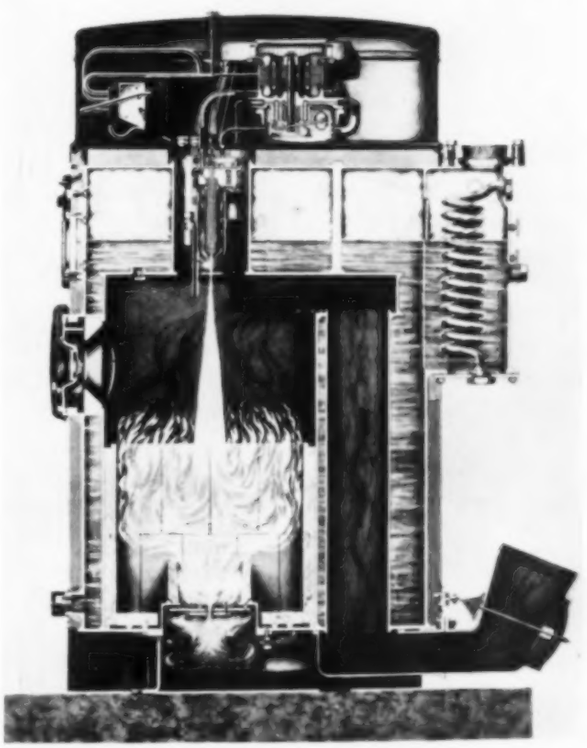
A portion of the combustion air enters the combustion chamber downward around the nozzle, but the larger part (the secondary combustion air) enters from the bottom, turning the down-coming flame back on itself and completing the process of combustion. Hot products of combustion pass out of the top of the combustion chamber, turn down and leave the boiler through a number of flattened fire tubes welded into the upper and lower head. This principle of standard boiler design is incorporated in order to absorb more heat and increase the efficiency of combustion; it is made possible by the utmost reliability of the materials of construction and the fabrication processes.

Flexible Copper Tubes

For ease of servicing and assembly, the burner head is a separate unit, connected to the compressor by two flexible copper tubes for air and oil. Ignition electrodes are built into the burner head and high voltage wires are eliminated by having the tops of the electrodes make direct contact with the ignition transformer terminals. The flame detector is an important separate safety device and is mounted on the oil burner head.

Automatic control is perfected to an unusual degree, unusual even to those familiar with the all-but-human devices installed for program control in heat treating departments. This, of course, is as it should be, for any failure in an oil-burning unit installed in a residence would be most annoying, if not actually dangerous. Such controls are too intricate to describe at this time; suffice it to say that (other than the more conventional control of steam pressure and hot water temperatures according to the requirements of the hour and season) they must provide a definite starting sequence and limit the oil furnace to three consecutive unsuccessful starts if combustion does not begin. Furthermore, in case the fuel fails to ignite, the oil discharge is limited to 4 sec. per starting cycle. In the event of flame failure from any cause, the oil supply must be permanently and immediately closed. Special alloys, fabricated to most exacting standards, are the foundation for all such control equipment.

Devices actuated by low water in the boiler



A Self-Contained Oil Furnace for Domestic Heating Requires the Most Advanced Design and Construction to Insure Reliable Operation Under Widely Fluctuating Temperature

Tensile & Bend Specimens Taken From Position Welds Made With 5/32-In. Electrodes. All fractures occurred outside the welds

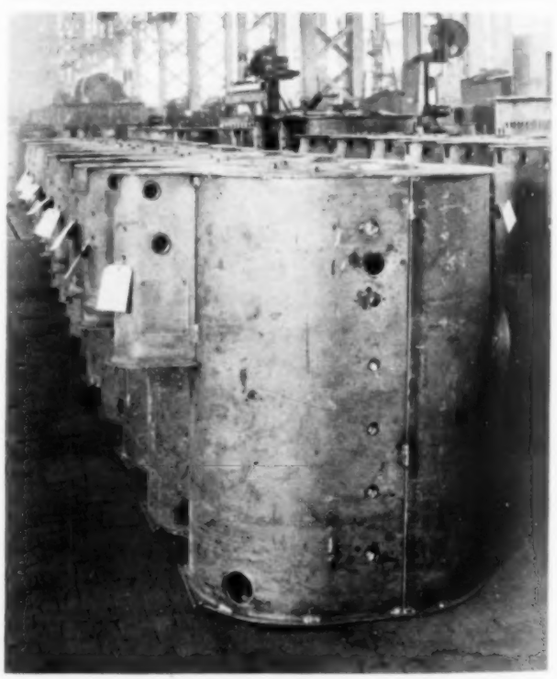
or undue pressure in the combustion chamber are interlocked to disconnect the power supply in case of abnormal operation. If any sudden expansion in the furnace chamber is caused by any unusual combination of circumstances, a door on the smoke flue opens, relieves the pressure to prevent damage to the chimney, and stops the oil furnace. Both of these devices require manual resetting, since their action indicates an abnormal condition which must be corrected.

Boiler Construction

The boiler itself is built by welding of fire-box and flange steel to meet the specifications of the American Society of Mechanical Engineers' boiler code. Either of these will procure the highest type of low carbon steel, amply proven by experience to be satisfactory for all steam boilers. Tensile strength must be between 55,000 and 65,000 psi.; ductility is high and phosphorus and sulphur are held to low limits.

The boiler proper is built entirely of steel in strict compliance with the Boiler Construction Code of the American Society of Mechanical Engineers. All joints are electrically welded so that the finished boiler is essentially one piece, with no chance for leaks. (Incidentally, it is interesting to note that the boiler is produced in a modern steel building which is itself of welded construction throughout and is equipped with every device for up-to-date tank and boiler manufacture.)

Welding has been developed into a carefully supervised production operation. Many of the long seams are done in automatic machines. Other operations, such as welding flues into the tube sheets, are done by hand. All welders are required to pass a qualification test before they are allowed to work on these boilers, and thereafter are constantly subject to the supervision of a licensed boiler inspector. Although regular use of X-rays for inspection purposes is not deemed necessary during fabrication, such a search-



Accurate Fit on All Seams Insures Rapid Welding of Tight Joints. Note staybolt heads to be welded into outer shell; also water heater at rear. This assembly is covered with insulation and a metal jacket before shipment

ing examination is periodically made of welds, chosen at random from the production line. Tests on welded joints broken in tension always fracture in the base metal; elongation in free bend test is from 30 to 50%. Tests on samples made from all-weld metal are found to range between the values given in the table below.

Methods of welding are selected to give the best results on the particular seam involved, and include the use of heavily coated electrodes, bare electrodes, and the atomic hydrogen arc. As above remarked, where the nature of the seam permits, automatic machines are used. Great care is exercised to prevent porosity in the welds and thereby insure a weld which will withstand corrosion. Corrosion tests made by approved laboratory methods indicate that the resistance offered by weld metal is within 95% of the corrosion resistance of flange steel.

Welding speeds vary from 2½ to 12 in. per min., depending on the method used and the nature of the seam. Proper fitting of the plates before welding is, of course, essential to a good job, and for this reason close tolerances are maintained in the production of the component parts.

All boilers are given three tests of 60 psi. hydrostatic pressure during construction. The first test is to check the welds between tubes and tube sheets. (Tubes, incidentally, are themselves made of flattened seamless boiler tubing.) The second pressure test checks the strength of the interior of the boiler, that is, the combustion chamber and tube assembly. The third is the final test on the complete unit; this is done by a licensed boiler inspector who stamps the boiler to show that it meets the Code.

Test Pieces Made of All-Weld Metal

Yield point	50,000 to 55,000 psi.
Ultimate strength	60,000 to 70,000 psi.
Elongation in 2 in.	20 to 30%
Reduction of area	35 to 50%
Charpy impact	20 to 30 ft-lb.
Specific gravity	7.82

Construction of Boiler Is Indicated by This Photograph of an Automatic Welding Head Attaching the Lower Flue Sheet to the Main Combusion Chamber

A recent special test with accurate strain gages showed practically no deflection of the plates of the boiler at the working pressures of 15 to 30 psi. At the testing pressure of 60 psi. the maximum deflection of the upper tube sheet was 0.011 in., and at 260 psi. the deflection was 0.055 in. These tests show that this welded construction is of a design fully capable of withstanding any load which will be put on it in service.

The same careful selection of materials and methods is exercised on the compressor, burner head, control, and other parts of the furnace. For example, there are certain connections in the burner head that may cause trouble from leakage of oil if not properly made. These joints are sweated together after careful tinning, so that the vital parts are hermetically sealed. Special silicon steels are used for all parts of the burner head and control in close proximity to magnetic fields to prevent the retention of magnetism between cycles.

WHY DO SOME METALS RESIST OXIDATION???

By K. Heindlhofer and B. M. Larsen
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United States Steel Corp.
Kearny, N. J.

UP TO A generation ago there was no common metallic alloy known which would resist heated atmospheres without wasting away rapidly into scale. Of course platinum was a good resistor, but this was entirely too expensive for common use. Discovery of the high nickel-chromium alloys and the high chromium-iron alloys has corrected this situation. While not cheap, these materials can be applied fairly freely, and important industrial processes and operations are now contingent on their stability.

An inquiry into the mechanism which enables these favored metals to resist hot oxygen and sulphur is useful as a guide toward the discovery of other alloys of similar nature. It is a complex inquiry, as will appear. Nevertheless it may be said that resistance to oxidizing environment at either atmospheric or elevated temperatures is due to an ability to form a highly impervious, self-healing, adherent, and hence protective film or layer of oxide; at atmospheric temperatures this film is so extremely thin as to be transparent to light, whereas at higher temperatures it grows to a scale of visible thickness, the rate of growth depending upon the alloy composition and the temperature. The relation between scaling rate and composition of these complex alloys becomes clearer by considering the rate of scaling of a pure metal, in which case the process can be treated by mathematical equations based on simple reasoning.

Conditions requisite for a protective oxide coating at high temperatures are:

1. The dissociation pressure (or pressure of oxygen in equilibrium with the oxide) of the metallic oxide at the particular temperature must be less than the partial pressure of oxygen in the atmosphere in contact with the metal.

2. The oxide formed must not be so volatile at the temperature that it evaporates from the metal surface and thus permits oxidation to continue unhindered.

3. The relation between the heat of oxidation (or combustion) of the metal and the speed of oxidation must be such that the temperature of the oxidizing surface does not rise to the melting temperature of the oxide, otherwise the oxide would run off, and the metal burn up.

Dissociation Pressure

The so-called noble metals, platinum, gold, silver, do not oxidize when heated simply because the oxygen pressure of their oxides is far greater than that of the atmosphere, so that any oxide formed would quickly decompose. For the more common metals the values of dissociation pressure within the scaling range (say 750

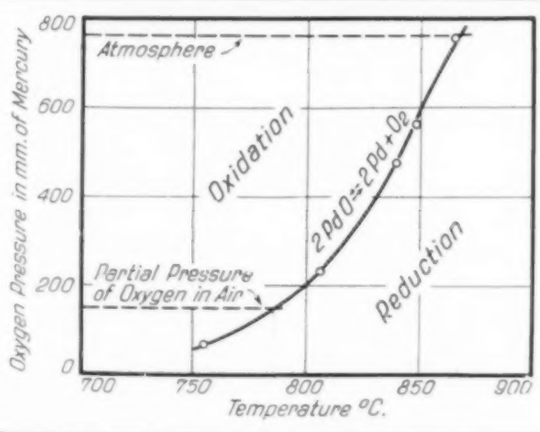
to 2200° F.) are much below this level, and hence they tend to oxidize readily.

In some cases the oxygen pressure is close to that of air, so that at some temperatures the dissociation pressure exceeds the level in air (0.2 atmosphere). For instance, as shown by the curve in this column, this happens for palladium oxide at about 1445° F.; below this temperature palladium oxidizes in air, above it it does not. Likewise Fe_2O_3 heated in air decomposes at about 2417° F. into Fe_3O_4 and oxygen.

Some metals, such as tungsten or molybdenum, form oxides which are quite volatile at the higher temperatures; consequently they burn away rapidly because of the continuous evaporation of oxide. This happens to the heated tungsten filament of an incandescent lamp when air is admitted to the bulb. Iron wire or thin iron sheet at a red heat burns brightly when exposed to oxygen, because the heat of oxidation raises the temperature of the oxide to its melting point, and it drains off, affording little protection to the metal remaining.

The foregoing discussion shows that a number of conditions must be satisfied before the formation of a compact protective coating of increasing thickness, resulting in a slower and slower rate of oxidation. As soon as a continuous film of oxide has formed over the surface of the metal, the scale can grow thicker only to the extent that oxygen atoms can, by passing through the scale already formed, reach unoxidized metal atoms beneath. This rate is determined by the rate of diffusion of oxygen through the scale, and this rate depends upon the nature of the scale itself, as well as upon the temperature. On some metals, such as chromium, the scale is quite impervious, and scaling is slow.

The precise factors which determine whether an oxide film is, or is not, continuous and impervious have not yet been established; consequently the actual diffusion rate can be ascertained only by trial. It is to be remembered that the actual rate may depend markedly upon the precise conditions under which the scale was formed. Moreover, the useful life of a metal at temperature may be very much less if it is heated intermittently than if heated continuously, unless the scale adheres very tightly to the metal.



At Pressures and Temperatures Above and to the Left of Curve, Palladium Metal Will Oxidize. At pressures and temperatures to the right palladium oxide will decompose into metal and free oxygen

Scaling of a Pure Metal

Diffusion of oxygen through scale to reach metal beneath is identical in principle with the familiar diffusion of carbon through steel in the processes of carburizing and decarburization. It can go on only so long as the concentration of oxygen at the outer surface of the scale is greater than at the interface between scale and metal.

More specifically, the concentration gradient of oxygen across the thickness of the scale layer is the driving force of the process, and the mathematical formulation of this fact is known as the Fick diffusion law. The mathematical development for the simplest case of a pure metal at constant temperature, leads to the conclusion that the rate of scaling is proportional to the square root of the elapsed time. This proves to be in accordance with the observations, and gives a quantitative expression for the slowing down of the process as the thickness of the scale increases.

The results of experiments on the rate of scaling of iron at various constant temperatures are plotted in the figure on page 36, taken from some work by the present writers, printed last year in *Transactions*, A.S.S.T. Log-log paper was used because it pictures a large range of the variables with constant percentage accuracy, and because the graph of the mathematical equation representing rate of scaling is a straight line on it for any one temperature. The irregularities in the course of the experimental curves correspond to local irregularities in scaling, such as the formation of blisters; there is, however, an unmistakable tendency towards the square root relationship described above, which is represented by the solid lines.

On this basis the difference in rate of scaling of a metal or alloy depends upon the differ-

ence in the rate at which oxygen can diffuse through the scale formed under the conditions of experiment. A low rate implies that the scale is compact and impervious, as well as adherent, as in the case of chromium (or aluminum or silicon) which, far from being "noble," in reality oxidizes more readily than does iron. For this reason, chromium, when alloyed with iron in proportion above 10 or 12%, brings about a very large increase in the resistance to scaling.

At first thought one might expect that it would be better to add some element, such as platinum or gold, which does not oxidize, or nickel which oxidizes less readily than iron. These metals will protect iron if plated over its entire surface as a continuous coat of the pure metal, but if alloyed with iron they have little effect, because the iron, by oxidizing more readily, builds an iron oxide scale around the particles of the more noble alloying element. For example, addition of 30 or 40% nickel lessens the scaling rate of iron by only 60 or 70%.

Scaling of Chromium-Iron Alloys

With enough chromium, however, the tendency is for it to oxidize first, in preference to the iron, forming a layer rich in chromium oxide which hinders further oxidation because oxygen and iron atoms cannot diffuse through it easily. This preferential oxidation obviously brings about a considerable change in the composition of the *metal* adjacent to the scale. Thus it is not surprising that the rate of scaling of an alloy deviates from proportionality with the square root of elapsed time, a relation which implies a constant composition both of the metal at the interface and of the scale. Nevertheless the relationship given above for the pure metal is useful as a first approximation, and as an aid in planning experimental work.

The rate of scaling in service is influenced by many more or less uncontrollable factors, such as blistering of the scale, loosening of the scale by rapid heating or cooling, or mechanical deterioration of the metal. Any of these alters the course of the process from the ideal. Nevertheless it is helpful to have comparative values obtained under controlled laboratory conditions. Such data for some representative iron-chromium alloys are depicted in the figures on page 37, the logarithmic scale being the same as in the figure for iron (except that time is expressed in hours instead of in minutes) so that the curves are comparable directly.

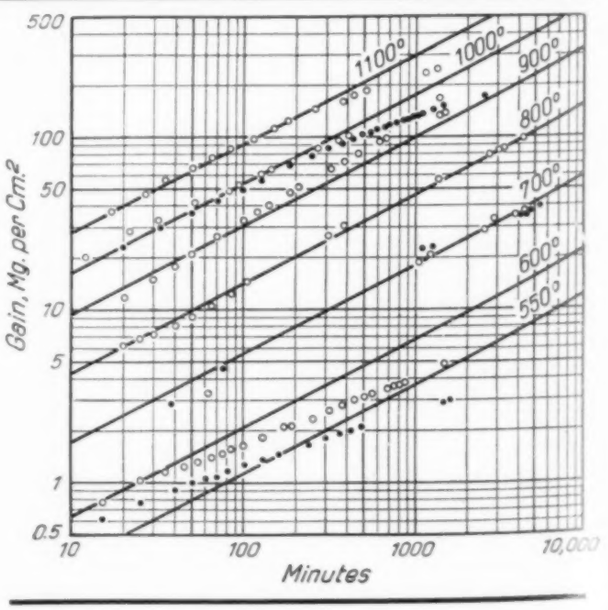
Obviously the scaling of these alloys does not follow the square-root law with respect to elapsed time, nor is the slope the same for the same alloy at different temperatures.

In general, the resistance of the high chromium-iron and iron-nickel alloys is many times greater than that of pure iron. The order of magnitude of this ratio is about 1 to 100, if thickness of scale in a given time interval is compared, and 1 to 10,000 or more if the time of formation of a given thickness of scale is compared. The 5% chromium steel is little better in air than iron itself at 1652° F., and this was also found to be true at temperatures as low as 1300° F. The 12% alloy scales slowly even at 1650° F.. At still higher temperatures the 17% or 28% chromium-iron alloy is preferable.

Resistance of the iron-nickel-chromium alloys to scaling is due mainly to their chromium content; in general, for a given percentage of chromium the alloy without nickel scales more slowly than that with nickel. The curve representing 18-8 is worthy of comment. It had scaled very slowly over a considerable period when the scale suddenly started to form in localized nodules, with the very marked increase in the over-all rate.

The comparatively few data available on

Record of Observations on the Scaling of Commercially Pure Iron at Various Constant Temperatures Between 550 and 1100° C. Lines are drawn to the slope required by the theory that rate is proportional to the square root of the elapsed time



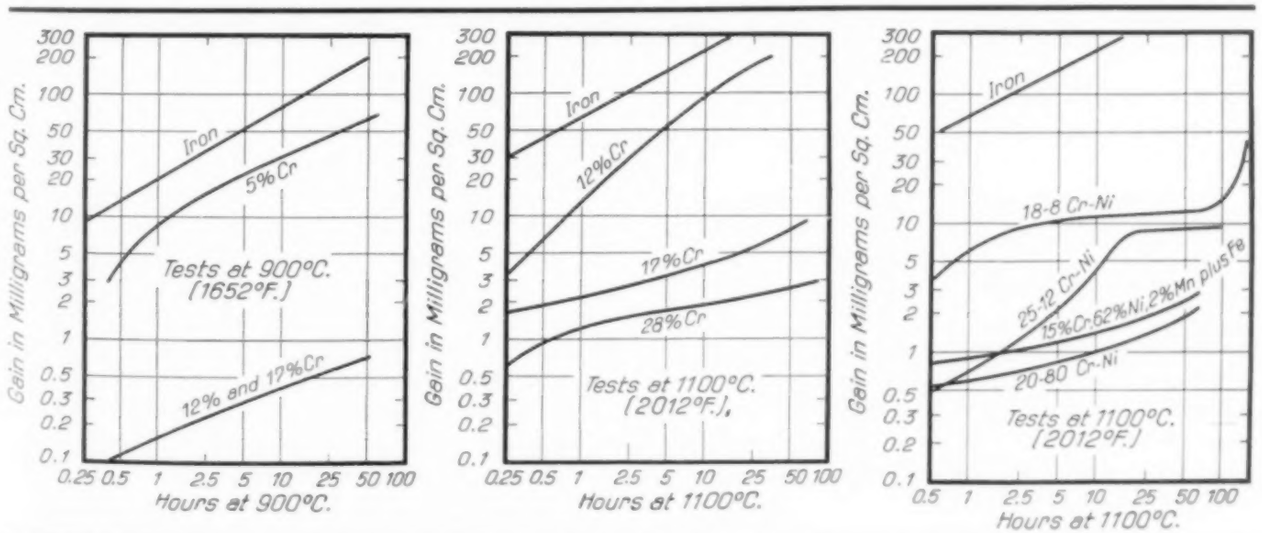
the rate of growth of either sulphide scale, or of a mixed sulphide-oxide scale, hardly permit one to make general statements. It is important to keep in mind the distinction between scaling in hydrogen sulphide, either pure or mixed with non-oxidizing gases such as nitrogen or hydrogen, and in mixtures of hydrogen sulphide or sulphur dioxide with oxidizing gases such as oxygen, water vapor or carbon dioxide. In the former, the scale is composed of sulphides of the metal or metals present. In the latter, the scale is generally a mixture of sulphides and oxides, and both its composition and its rate of growth will vary with (*a*) the relative sulphur content of the gas phase, (*b*) the metal composition, and (*c*) the temperature.

A study of the behavior of pure metals in reducing gases containing hydrogen sulphide is badly needed. An important condition here is the fact that the eutectic melting temperatures in the iron-sulphur, nickel-sulphur and copper-sulphur systems all fall in the range in which metals are sometimes heated in service. Nickel is known to be badly attacked in hydrogen sulphide, but above the eutectic temperature (1180° F.) the scale becomes partially liquid and the rate of corrosion suddenly jumps up.

Iron is also attacked severely by hydrogen sulphide. A recent study of iron and iron-chromium alloys in this gas at 1375 to 2000° F. by Rickett and Wood in *Transactions* for April, indicates that the protective effect of chromium against sulphide scaling is much less pronounced than against oxide scaling. They note that "when these results were plotted using logarithmic coordinates the points were found to follow straight lines within the limits of the experimental error." Other data support these results qualitatively. A moderately increased resistance due to chromium and a tendency toward a decreased resistance due to nickel is all that can be said.

Hatfield has also published some information in *Journal* of the Iron and Steel Institute in 1927 about metals in an atmosphere of sulphur dioxide at temperatures from 1300 to 1800° F. Pure iron, nickel and cobalt were badly scaled, while copper and chromium were relatively resistant. Among the alloys, low carbon steel, 3% nickel steel, 36% nickel-iron alloy, 60-15 Ni-Cr electrical resistor alloy, cast iron, 15% silicon-iron and monel metal were all attacked more severely in sulphur dioxide than in oxygen. A 12% chromium alloy was attacked rather badly, but 8% chromium steel, 3% silicon steel, 18% chromium-iron alloy, 18-8 Cr-Ni alloy, a steel containing 16% chromium, 8% nickel and 4% silicon and another 18-8 with 4% tungsten all resisted attack by sulphur dioxide over this temperature range comparatively well.

Apparently, in such mixed oxidizing plus sulphidizing conditions, chromium in amounts above 15 to 18% in iron alloys gives rather effective protection, while nickel in iron alloys, in the absence of chromium (or even with chromium in very high nickel alloys) resists very little better or even not as well as carbon steel.



Representative Curves for Time-Scaling Data Obtained on Chromium-Iron and Chromium-Nickel-Iron Alloys in Air at 900° and 1100° C. (respectively 1652 and 2012° F.)

CORRESPONDENCE . .

. . AND FOREIGN LETTERS

Similarities Between Abnormality and Aging

PARIS, FRANCE — A general statement may be made that steel offers two possibilities of hardening that come from the existence of two kinds of solid solutions of carbon in iron, first the gamma solution or austenite and second the alpha solution or ferrite. In both of these solid solutions, the solubility of cementite (or some phase containing carbon) increases with temperature. It is thus possible to obtain at room temperature three successive conditions for each solution by an appropriate heating or cooling:

1. Supersaturated solutions, not in physico-chemical equilibrium. These two correspond to the "hyperhardened" condition of the gamma or alpha solid solutions, respectively.

2. The next recognizable modification is believed to be due to a fine precipitation from these supersaturated solutions. This corresponds to quench-hardening as long practiced in industry. These states are in chemical equilibrium but very far from structural equilibrium, since the precipitate is extremely finely dispersed.

3. Lastly as the precipitates coalesce from the preceding states, we approach structural equilibrium. This condition includes tempered and stabilized steels.

Phenomena of groups 2 and 3 parallel each other in both the gamma and alpha solutions, and depend on the same laws — more particularly those ruling precipitation and coalescence. The reactions are accelerated by factors having a physical effect such as temperature, pressure or deformation, and surface stress.

On the other hand, since hardening due to the existence of either the gamma or alpha solution comes from supersaturation, it depends on those factors that influence supersaturation, namely, diffusion speed in solid solution, presence of nuclei, or the joints between grains. From these considerations it can be shown that the effect of an addition element in the alloy on the phenomena of hardening (or the reverse — on the more or less easy attainment of physico-chemical or structural equilibrium) will be at least three-fold:

1. An effect on the diffusion speed — either a retardation (hardening effect) or an acceleration (tempering effect).

2. An effect on the grain size. If it promotes fineness, it increases the extent of the joints; this corresponds to a precipitating effect — that is to say, promotes tempering.

3. The production of a cloud of fine particles acting as nuclei (for instance, vanadium, aluminum, or silicon may produce fine oxidized inclusions) which also impede grain growth by mechanical obstruction. Consequently such phenomena promote the tempering reactions.

Of course, these influences may overlap and conteract.

It is thus possible to expect a relationship between the phenomena connected with hardening and tempering as it is known in tool steel and aging of low carbon sheet steel — a matter which is thought to be connected with changes in the predominating ferrite — if one admits a similarity between the sundry factors which have an influence on the hardening of gamma and alpha solid solutions.

Thus "abnormality" as defined by the McQuaid-Ehn carburizing test is nothing else than the structural tempering effect when cementite coalesces in the gamma solution — it opposes, consequently, the gamma hardening. All "anti-hardening elements" (those refining the gamma grain, those producing fine precipitates or inclusions) promote abnormality. Such is the

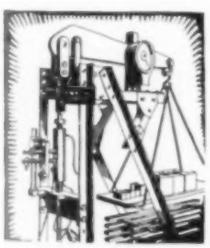
case for small additions of aluminum, vanadium, and similar metals in ordinary steels.

Similarly, aging of steel presents all the characteristics of the structural hardening of alpha solutions. It may be represented, for instance, as a function of temperature and time, by the characteristic curves already given in METAL PROGRESS, August, 1931. Such steels may be stabilized either by maintaining them in the supersaturated state without precipitation or, preferably, by subjecting them to a steady and mild tempering condition where coalescence occurs. For the latter one may resort to a thermal tempering, or else add some elements which accelerate tempering — that is to say, some elements which would promote abnormality in carburized steels. Consequently, it may be expected that small additions of aluminum, for example, will suppress aging effects, which is confirmed by experience.

It seems interesting to point out this parallelism of action between phenomena having no apparent connection, for it enables us to foresee the entire action of some factors of which a few effects are known and at the same time to give a logical interpretation to experimental findings.

All the above considerations are proven by studies carried on at the laboratory of Aciéries d'Ugine, which have led to this practical conclusion: That it is possible to obtain, by means of adequate treatments and alloying additions, the required grain size, abnormality and stability against unwanted aging effects.

ALBERT PORTEVIN



Creep Strength of 18-8

H. C. Cross of Battelle Memorial Institute calls attention to one of those errors which escape "checking and double checking" by editor and author. In Dr. Norton's letter published in June, page 50, on "Creep Strength of 18-8 After Four Years' Service," the creep rates noted on the four lines plotted at the bottom of the page are ten times too great. The diagram at the top of the page is correct.

High Speed Welding With Large Electrodes

TURIN, ITALY — A noteworthy trend in European arc welding is strongly toward the use of larger electrodes.

Many specifications formerly required the use of electrodes of small diameter, at least for the first layers of metal in the deepest part of the notch. In many cases diameters as low as $\frac{1}{8}$ in. were used, with the object of insuring good penetration of the molten metal.

Experience has proved, however, that better penetration is obtained with properly coated electrodes when larger ones are used. The main reason for this seems to lie in the fact that the heat produced with small electrodes is not sufficient to insure complete melting of the base metal, especially when large and thick pieces are being welded. Furthermore, heating is localized in a relatively small volume of metal, which is rapidly cooled by its surroundings, thus inducing dangerous internal stresses.

On the other hand, the welding operation is easier and safer with electrodes of large diameter; the welder has no transverse swinging movements to make and may fix his attention on the steady advancement of the electrode along the weld. Under such conditions, the joint is more uniform. Likewise a greater intensity of current can be used, with which a continuous arc is more easily maintained.

Electrodes of diameters varying from $\frac{1}{4}$ to $\frac{3}{16}$ in. are used at present with excellent results. Corresponding currents vary from 350 to 500 amp. Direct current welding is practically obsolete, as its technical advantages (from the point of view of quality of welding) have been found to be negligible, and it is more expensive to install. Another advantage of large electrodes lies in the possibility of obtaining excellent results on plates of moderate thickness, square cut and simply butted, without any special preparation of the edges of the plates.

From the economic point of view, noteworthy advantages have been found. Work can proceed at a greater speed on large work with the same degree of safety. For instance, deposits 0.15 sq.in. in section can safely be made at a speed of 40 to 50 ft. per hr. Extensive and careful re-

searches on the properties of the metal deposited with $\frac{7}{16}$-in. electrodes at even higher speeds have shown excellent mechanical properties and great uniformity. With tensile strength above 80,000 psi. the reduction of area does not go below 55%, and resistance to impact always remains above 10 kg. per sq.cm.

It is evident that the use of larger electrodes requires special electrical equipment, but recent results have been so good that many works are modernizing their plants in this respect by scrapping old welders and buying new ones.

FEDERICO GIOLITTI

Enriched Air for Open-Hearth Furnaces

GROSNY, U.S.S.R. — A pair of heats in Soviet steel foundries have been made to determine whether certain theoretical advantages of oxygen-enriched air supply could be achieved in practice. Several lengthy discussions as to the effect of oxygenated air on the manufacture of open-hearth steel have been published, but actual experience is almost wholly missing. Therefore, the following fragmentary data may be useful to metallurgists elsewhere.

It is readily agreed, of course, that the chief purpose of adding oxygen to the air required for fuel combustion is in order to increase the amount of heat liberated in the open-hearth furnace and to raise the temperature of the flame, especially during melting. Economical advantages would be a shortening of the time of melting and a corresponding increase in output from a given plant. Metallurgically, there should also be some effect on the oxidation of metal during melting, and the speed of elimination of carbon, silicon, and phosphorus.

It would appear that there will be certain practical limits of the flame temperature other than the danger of melting the furnace refractories. These reside in the fact that in the first part of the heat the fuel burns under unsatisfactory conditions, since the free volume of the melting chamber is encumbered with a cold metallic charge of bulky scrap. The latter chills the incoming gases and does not allow ample space for normal combustion and proper movement of the flame. This results in incomplete combustion of any fuel which produces a long flame; oxygen may remedy this state of affairs, at least in part.

The first test was made in a 4-ton oil-fired furnace at the "Hammer and Sickle" steel foundry in Moscow. The second test was in a 10-ton oil-fired furnace at the Sormovo steel works near Gorky. Both furnaces had regenerative chambers for air supply. Oxygen was from a bank of cylinders of welding gas. In the first test 58 cylinders were used, the gas being introduced directly into the furnace near the bridge; in the second, 30 cylinders of oxygen were injected into the compressed air line used to atomize the oil and tarry residue used for fuel.

Results were interesting. In the first test about 6200 cu.ft. of oxygen (measured at atmospheric pressure) was put into the furnace during the first hour, 3300 cu.ft. in the next hour, and 2500 cu.ft. during the remainder of the heat (4.5 hr. total time). During melting the oxygen content in the air entering the furnace was about 27%; the average for the entire heat was about 24.5%. Compared with a normal heat in this furnace, 40 min. was saved in melting. A considerable part of the oxygen apparently combined with the metal and it was found necessary to add an unusual amount of pig iron into the bath. Carbon in the metallic charge was oxidized about 50% quicker than when the smelting process was carried out in the same furnace and under similar conditions without the addition of oxygen. The final metal was entirely normal, analyzing 0.30% carbon.

In the second test on a larger furnace the oxygen was more rationally utilized for the combustion of the oil residue, and the metal (44% cold pig, 56% steel scrap) was not so highly subjected to oxidation during the melting process. About 6000 cu.ft. of oxygen was used during the first 4 hr. of a 7-hr. heat. Average oxygen content of the air during the first part was about 25%. Melting took 25 min. less than normal. The first test ingot contained a large amount of carbon and it was therefore necessary to add iron ore for decarburization down to the required 0.13%.

Six tentative conclusions may now be stated from these tests, as follows:

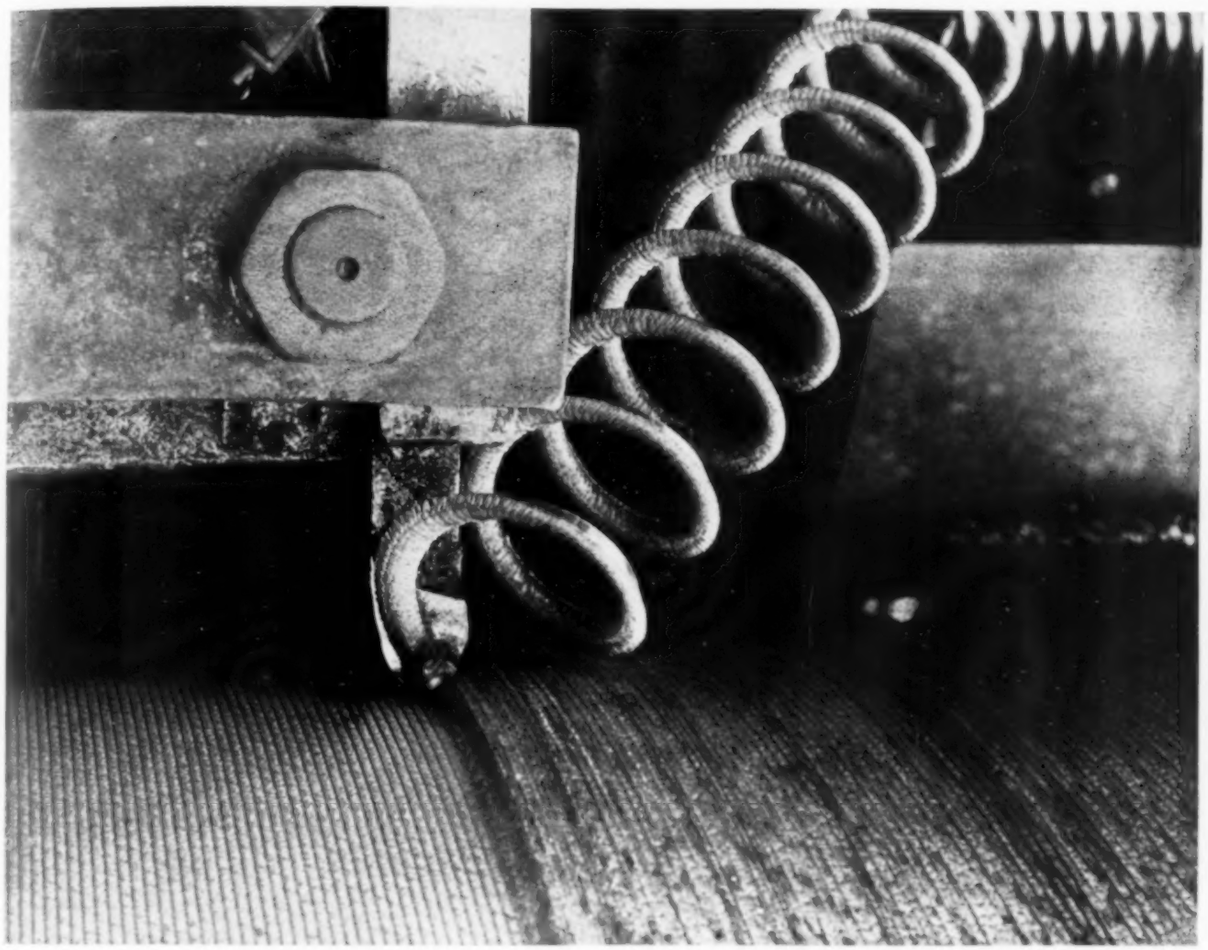


Photo by John P. Mudd for The Midvale Co.

1. A normal product was made.

2. Combustion conditions are improved during the melting period and the temperature of the flame is raised.

3. The time required to melt the charge is decreased, and thus the output of the furnace is raised.

4. No signs were observed that the furnace walls, roof or ports were suffering from the higher temperatures.

5. Depending upon the changed flame conditions, the working of the heat (pigging or oreing) will be changed materially, and this in turn may influence the time for a heat and the amount of ferro-alloys required at the finish.

6. The amount of fuel consumed during both smelting tests was somewhat more than that required in the usual practice, but whether this is more than an accident cannot be said, from the limited tests carried out.

B. M. Suslov

English Tool Steels Differ in Some Respects From American and Continental

SHEFFIELD, England — The article on "Materials for Modern Cutting Tools" by J. V. Emmons in the December issue of Metal Progress is very useful as an indication of American tendencies in the field, and as a means of comparison of American practice with British and European practice.

As regards British practice, the distinction between carbon tool steels and low alloy steels has no sharp division. The most representative use of plain carbon tool steels is perhaps that of the steel used for files, that is to say, one containing 1.2% carbon with low silicon and manganese. Lower carbon contents are used for a variety of purposes where the final condition is, in general, not required to be so hard as the file.

Modified steels, with small additions of one

or more of the elements — tungsten up to 3%, chromium up to 3%, molybdenum up to 1% — are in use, generally with carbon percentages not much above 1% for tools where either greater depth of hardening is required, or where a somewhat tougher condition is desired than is given by a plain carbon steel.

"Non-distorting" steels — usually oil hardening — are of several varieties, containing chromium or manganese or both, the use of 1.5% manganese probably being in greater favor. It should be clearly understood with regard to carbon steels or low alloyed steels that "quality" as well as analysis plays a large part. There is still scope for high quality steels made in the crucible from pure base materials in both these classes of tool steels. Tool steels made in the Siemens open-hearth furnace which are used on classes of work where cost is more important than quality, are admittedly inferior, where high class tools are in question.

With regard to high speed steel, 14-4-1 and 18-4-1.5 are more or less standard. The more recent development has been in the direction of increased cobalt, in a range around 6% or from 10 to 15%, while the use of higher tungsten contents (up to 24%) is not now looked upon with so much favor as formerly. With regard to the carbon content of high speed steels, British practice is apparently intermediate between American and Continental, values of 0.60 to 0.75% being perhaps most common.

Tool steels for special purposes (such as dies and tools for hot work like shearing hot plates) have been developed and are of two main types: *(a)* Medium high tungsten steels containing chromium, vanadium and other elements to make them a "mild high speed steel" and (*b*) high carbide containing steels such at 12 to 14% chromium with 1.5 to 2% of carbon and other alloy additions. The latter has very good abrasion resisting qualities, whether cold or at moderately elevated temperatures.

With regard to the use of "carbide" tools of the newer hard carbide materials, the use of these in Great Britain is extending steadily, but it is too early to state what their position will ultimately be in relation to the more usual types of tool materials.

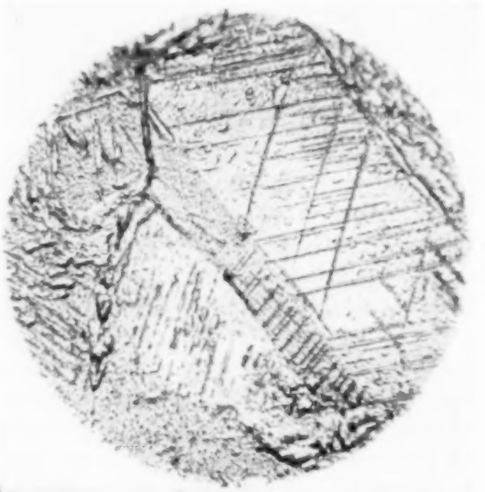
W. H. Hatfield

Neumann Bands in 18-8

NICETOWN, Philadelphia — It is well known that mechanical twinning, resulting in the formation of Neumann bands, frequently occurs in the ferrite of low carbon steel. Other metals are known to be subject to the formation of mechanical twins; for example, tin, zinc, cadmium and the kamacite of meteoric iron. I have frequently suspected the presence of Neumann bands in austenite, but know of no published reference to it. Recently I have had the opportunity of examining at the Research Department of The Midvale Co. specimens of 18-8 from a structure destroyed by an explosion and have observed, at low power, markings which I suspected to be Neumann bands.

Magnification at 1000 diameters, as shown in the adjoining photomicrograph, reveals them certainly as Neumann bands — no doubt produced by the shock of the explosion.

Francis B. Foley



Nature of a Solid Solution

SENDAI, Japan — The nature of solid solutions is a subject of profound interest, because many important effects of heat treatment are principally attributable to the changes which occur in them. X-ray investigation has shown that the crystal structure of a solid solution (as a little chromium in iron) is generally similar to

that of the solvent (iron) and an atom of the solute (chromium) replaces an atom of the solvent in the lattice. According to this idea all atoms in such a solid solution are structurally equivalent, the atoms of the solute being distributed more or less uniformly throughout the parent lattice.

This theory may be tested by measuring the lattice parameters of solid solutions, computing their density from these data, and comparing the result with the density measured by Archimedes' method. Phelps and Davey have done this for a silver alloy containing 4.34% aluminum. Its density, calculated from theory, was 9.483, a figure correct to ±0.07%. Actually the alloy had a density of 9.362.

In order to explain this discrepancy, they assume that the solid solution represents actual chemical composition between every aluminum atom and the surrounding silver atoms as the compound Ag_3Al. However, if *all* the aluminum were in this compound and mixed mechanically with unstrained silver, the density would be 9.5.

A more logical explanation appears to be the presence of pinholes in the solidified alloy. It is common knowledge of assayers that molten silver will absorb gas from the air and will "spit" or "sprout" when partly solidified. Actual and careful experiments, both in melting and solidifying in a vacuum, or under potassium chloride, did not produce a sound ingot.

Hence an alloy containing 4.5% aluminum was prepared by S. Kokubo at the Research Institute for Iron, Steel and Other Metals, using "chemically pure" silver (Kahlbaum) and the purest aluminum provided by Aluminum Co. of America. The sample was melted in the same manner as that employed by Phelps and Davey, and heated in a high vacuum for several hours at 850° F. After measuring the density it was strongly pressed in a hand press, being careful to avoid cracking the specimen. Its density was then remeasured. This sequence of vacuum annealing and compressing was continued until the specific gravity reached 9.4204. When annealed the value of 9.4228 was recorded — this is due to relief of internal strain.

Now if the added aluminum is assumed to be dissolved by atoms in solid silver, the lattice parameter would have a value of 4.049 Angstrom units (according to Phelps and Davey) and the calculated density would be 9.450. The difference between observed and calculated values is less than 0.3% and can reasonably be explained by the presence of a small quantity of Al_2O_3 in the alloy.

On this basis, the discrepancy between the experimental density and the calculated density does not afford any ground for the hypothesis that the aluminum in the solid solution is chemically combined with silver.

KOTARO HONDA

Vacuum Melting on a Large Scale

SCHWEINFURT, GERMANY — Undoubtedly the art of melting and casting metals and alloys in a vacuum has been most highly developed in our country by the Heraeus Vacuum Smelting Co. in Hanau, a subsidiary of the Heraeus Platinum Works, well-known for its products used by scientists everywhere.

The theory of vacuum melting is old, and other organizations in Germany have sought to convert the theory into practice, but it was W. Rohn of Heraeus' staff who finally succeeded in bringing vacuum melting to significant technical utility. The first impetus was felt during the War when platinum was very scarce and strictly rationed. For the manufacture of thermoelectric pyrometers for a multitude of essential operations up to 2000° F. it appeared necessary to depend on base metals. In such a temperature range only nickel and chromium and their alloys could be considered. However, uniformly pure and uncontaminated metal was necessary in order that the elements could be interchangeable and even useful without expensive and elaborate calibration of each thermocouple installation. Hence came the desirability of vacuum melting of the original ingot from which the wires were to be drawn.

The first vacuum melting furnace for commercial production, therefore, was built at the beginning of 1917; its capacity was only 5 lb. of metal! But truly reproducible alloys were successfully manufactured with it, alloys whose thermal electromotive force bore a fixed relation to

that of platinum vs. platinum-rhodium thermocouples within the working range to an accuracy of ± 15° or 20° F.

Soon after this initial success with thermocouple wires, production of lead-in wires for incandescent lamps was undertaken. Next came wire for dental purposes, and gas-free metals for X-ray tubes, and more recently alloys for radio tubes. It has been amply proved that base metals, when vacuum melted, can be prepared with the same degree of accuracy as was formerly possible only with the rare metals. The technical applications of the commoner metals have therefore been correspondingly increased.

An idea of the furnace development can be acquired from the following table showing the furnace capacities available in the respective years:

Year	*Capacity of Largest Furnace*
1917	9 lb.
1919	25
1920	50
1922	90
1924	500
1926	3000
1933	9000

To celebrate the tenth anniversary of its founding, the Heraeus subsidiary has issued a 440-page brochure recounting the developments in the decade just past — a book which will delight every metallurgist who can read German, recounting as it does the successful culmination of an enormous amount of scientific and technical work.

Vacuum melting in a coreless induction furnace involves two important features other than the mechanical difficulties of housing a large melting unit in an air-tight container and keeping it exhausted to very low pressure: (*a*) A method of pouring without breaking the vacuum, and (*b*) a satisfactory lining material.

The first is solved by building the mold as an extension of the pouring lip, and at the proper time tilting the entire unit so the metal is transferred from the melting basin into the ingot mold. In pouring into a mold under a vacuum, however, difficulties result from the fact that, without an air cushion, the metal being poured strikes so hard against the sides of the mold that it is soon destroyed. These difficulties led Dr. Rohn to build a special water-cooled copper mold, which has become more and more important in pouring technique. While cast iron molds can be used in normal steel manufacture for from 130 to 150 ingots, molds made of soft cast steel with high melting point and coated with insulation will withstand not more than three heats when pouring ½ to 2-ton ingots under a vacuum. However, as was noted in *Zeitschrift für Metallkunde* in 1927, several years passed before water-cooled copper molds were successfully manufactured.

Difficulties with linings occur because the entire furnace must be cooled before it may be opened to remove the ingot. Each melt, therefore, involves a wide temperature cycle in the lining. To avoid cracks it is necessary to keep the external portion of the lining in a plastic condition where it is in contact with the cooled conductors, whereas it must be adequately sintered on its inner surface in contact with the incandescent metal. This is done by ramming granular refractory mixed with a little nonvolatile binder inside a heavy steel form, and turning on the current so as to heat this form almost to melting, thus baking and fritting the very inside of the freshly tamped lining.

Dr. Rohn gave a lecture in 1928 before the deutschen Gesellschaft für Metallkunde on the properties of vacuum melted metals, which exhaustively discussed the subject of gases in metals. (A résumé of this lecture is given in *Zeitschrift für Metallkunde* in 1929.) One of the most notable properties of alloys melted in a vacuum is the improved ductility over alloys of the same composition melted in atmospheric furnaces — that is to say, vacuum melted metals and their alloys can be much more easily drawn to wire and rolled into sheet, strip, and seamless tubes. Great savings are made in the fabrication of very fine wire, for instance, by reducing the number of process anneals. Furthermore, some metals, like copper, which normally are made with considerable oxide inclusions, are weldable without damage if melted under such conditions as to be oxygen-free.

It is important, however, that a true vacuum be maintained in the furnace for a sufficiently long melting and degasifying period.

HANS DIERGARTEN

Various Forms of Graphite and Cementite in Cast Iron

LEOBEN, AUSTRIA — Judging from the great number of recent publications on cast iron, metallurgists are in general agreement on the most important facts as to its microstructure. There is, however, a regrettable confusion of terms, especially those associated with cementite and graphite appearing at different stages in the history of the sample. Consequently the following suggestions are made in the hope that they may, if adopted, lead to more precise thinking and descriptions without danger of misunderstanding. There is no need to abolish terms which have been in use for a long time, as for instance "temper carbon." But since this may sometimes be a mixture of graphites having four different origins, it is evident that one term like temper carbon is not sufficiently precise.

Primary Cementite; Primary Graphite: There is no doubt about the meaning of these two terms.

Eutectic Cementite is cementite which forms the metastable eutectic with austenitic crystals. In most cases it is not pure Fe_3C; it contains more or less silicon, manganese, and probably other alloyed elements.

Eutectic Graphite is graphite crystallized directly out of the molten state, simultaneously with the (later decomposed) eutectic austenitic crystals. Together they form the stable eutectic. This graphite usually appears in the form of needles (plates) of different length and thickness, and is found in pearlitic gray cast iron. If the needles are small enough and if there is no coarse primary graphite, the best tensile strengths are reached.

Decomposition Graphite is formed in the solid state by the decomposition of the eutectic cementite. Together with the decomposition product from the eutectic austenite, it forms a eutectic stable at low temperature, which, of course, is different from the one already mentioned. Decomposition graphite appears in finest nodules and needles of which the length and width are from 1% to 10% that of the eutectic graphite. It is to be emphasized that in most cases the matrix is also decomposed into ferrite, while the carbon contained in the decomposing austenite attaches itself to the decomposition graphite, increasing the latter's size a small amount. One might call this eutectic the "true stable eutectic," as the two components are the truly stable ones in the iron-carbon system, except for the difficulty that neither of them exists at the true eutectic temperature.

Secondary Cementite separates because of the difference of solubility of carbon in gamma iron between the eutectic and the eutectoid temperature (approximately 2080° and 1330° F. respectively). This cementite is also a complex carbide, Fe_3C, containing silicon and other elements. Under the microscope it may appear as straight needles in regions formerly occupied by austenitic crystals. Very often it cannot be found, as it is attached to the eutectic cementite in white cast iron or is decomposed.

Secondary Graphite: Graphite separating on cooling because of the diminishing carbon solubility (as in the case of secondary cementite). It very seldom exists alone; usually it appears together with decomposition graphite, as for instance in malleable castings if there is a pearlitic matrix with "free carbon." This latter, often called "temper carbon," consists in this case of decomposition graphite and secondary graphite.

Pearlitic or Eutectoid Cementite: There is no doubt about the meaning of this term. Pearlitic cementite is in most cases alloyed, like the other forms of cementite.

Eutectoid Graphite is the stable form of carbon corresponding to pearlitic cementite. Although it exists, it is seldom found because it is attached to the decomposition graphite and the secondary graphite; together with them it forms "temper carbon."

Tertiary Cementite is cementite separating from ferrite because of the diminishing carbon solubility in alpha iron from eutectoid to room temperature.

Tertiary Graphite is stable carbon corresponding to tertiary cementite. The latter two are very small in amount — usually submicroscopic — and of no great interest in cast iron.

One advantage of the above classification is that it contains within itself the generally accepted ideas concerning the stable and the metastable systems, and that with obvious modifications it can be applied to the newer alloyed cast irons.

ROLAND MITSCHE

BOOK REVIEWS

THE CHEMISTRY OF SOLIDS, by Cecil H. Desch. 213 pages, 6x9, bound in blue cloth. Cornell University Press, Ithaca, N.Y. Price $2.50.

DR. DESCH was for many years professor of metallurgy at University of Sheffield, England, and since then has become head of the metallurgical section of the National Physical Laboratory. In the interim he was at Cornell (fall of 1931) acting as the Baker Non-Resident Lecturer in Chemistry and the present book contains the substance of the lectures delivered then.

In view of Professor Desch's interests, much of the content of this book has to do with metallic solids, and in fact with the *physics* of the crystalline state rather than the chemistry thereof. Consequently, the book has great interest to metallurgists; furthermore the text is very easy to read, and inquiring students can consult hundreds of sources mentioned in footnotes. For instance, in the chapter on "The Crystal Boundary," evidence is gathered from the literature of the whole scientific world showing how little we really know about that subject. Actual nature of the intercrystalline cement has most practical value on its relationship to the strength of metals; Dr. Desch evidently does not believe in the amorphous theory, for he observes that "since it has been shown that atomic attraction is practically insensible at a distance of two atomic radii, it is unlikely that liquid molecules trapped between two growing crystals would be so equally attracted as to remain in a random arrangement."

Another most interesting lecture has to do with the mosaic structure in crystals — those subcrystalline units which are suggested by many metallographic prints of coarse crystalline metal, either lightly etched, or deeply etched into pits, and by the regularity of slip bands after plastic flow. Many lines of reasoning support this inference; for instance, their presence explains certain anomalies observed in X-ray diffraction figures. Again, if these units have weak borders — quasi cracks — the fact that metals are so much weaker than their atomic cohesion would seem to require, is explained. "One is almost compelled to assume the existence of such loosened regions in order to explain the phenomena of diffusion in the solid state," says Dr. Desch. *(Continued on page 48.)*

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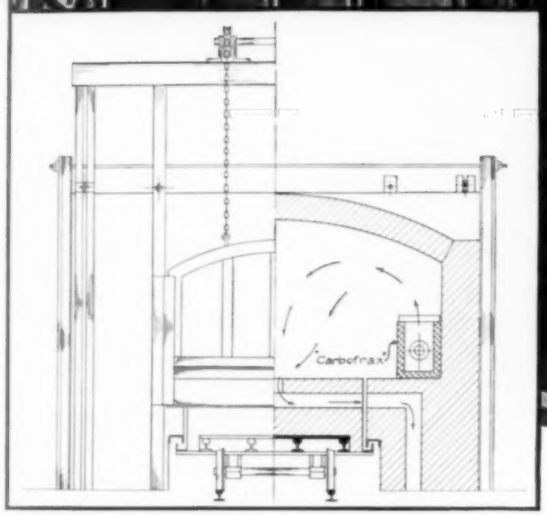

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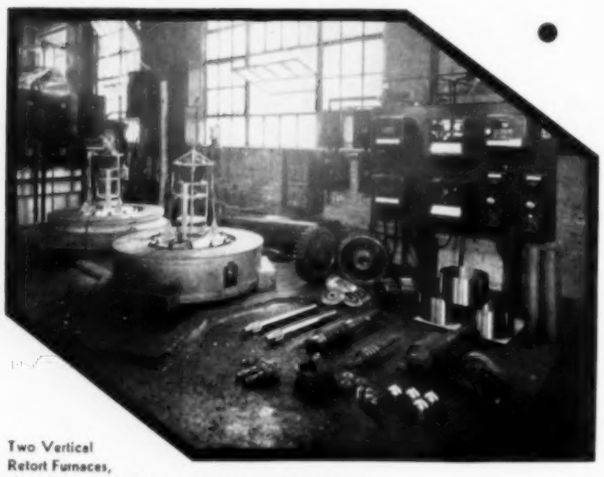

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BOOK REVIEWS

The real nature of martensite (about which there is a most voluminous literature) also deserves a chapter. Dr. Desch briefly cites the evidence derived from recent experiments on thermal changes during the quenching of fine austenite wires in blasts of compressed hydrogen. Moving pictures also show the instantaneous development of full-sized martensitic needles in crystals of austenite. An ingenious explanation is also given of how the space lattice changes from face-centered iron to body-centered iron, and of the origin of the Fe_3C molecule. Dr. Desch concludes that, simultaneously with the transformation from gamma to alpha iron, carbon atoms formerly dissolved in the austenite unite with iron atoms forming molecules of Fe_3C (cementite) deposited along definite crystalline planes in thin sheets, perhaps as little as one molecule thick. Hardness of martensite is explained partly by the lattice distortion during changes of volume during the transformation, and partly by lattice distortion due to the existence of these cementite molecules (and not to the extreme fine grain of the ferrite, as is commonly supposed). Changes in magnetic properties, density, conductivity, and hardness with changing thermal treatments all conform to this theory.

* * *

LA CRISTALLISATION DES METAUX, by N. T. Belaiew. 129 pages, 5½x8¼ in., paper back. Institut de Soudure Autogène, Paris. Price 20 francs.

IN this little book, Col. Belaiew summarizes his researches on the crystallization of metals which started in his native country over 30 years ago, under the direction of Prof. Tschernoff, as an inquiry into the laws governing the solidification of steel in a mold. His pioneering investigations have been carried along by many others in many lands. Witness the very extended studies about ingot practice still under way by the Iron & Steel Institute's committee in England, and the researches of Mehl and his associates in Pittsburgh on the Widmanstätten structure. The high quality of the original investigations may be appraised from the fact that they clearly indicated the existence of a high temperature transformation of iron, just under the melting point, long before the delta modification of iron was experimentally established.

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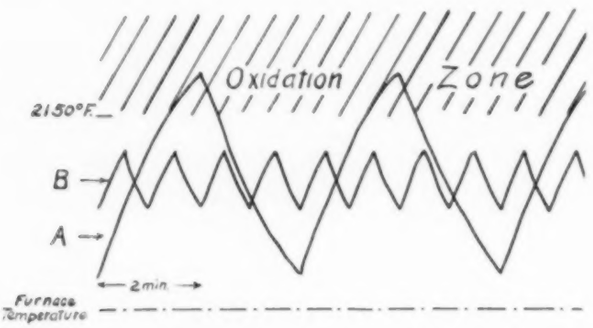

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Carpenter Steel Co. offers (to manufacturers in U. S. A. only) a handy pocket size slide chart which gives at a glance a summary of technical data on all Carpenter stainless steels. Bulletin Se-12.

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In a carefully prepared booklet of Aluminum Co. of America, effects of various corrosive agents upon aluminum and its alloys are described in detail. It is an excellent source of information on this subject. Bulletin Sp-54.

Zinc Plating

Those interested in plating will find interesting material in a booklet of the R. & H. Chemicals Dept. of du Pont which describes plating with Duozinc, a mercury-containing zinc anode with marked production properties. Bulletin Ar-29.

Heat Treating Manual

A folder of Chicago Flexible Shaft Co. contains conveniently arranged information on heat treating equipment for schools, laboratories and shops, and also illustrates the several types of Stewart industrial furnaces. Bulletin Ar-49.

Bright Annealing

Electric Furnace Co. tells about their controlled atmosphere furnaces for continuous deoxidize annealing, bright normalizing and annealing ferrous and non-ferrous metals. Work comes clean, bright and dry from these furnaces. Bulletin No-30.

Heat Resisting Alloys

Authoritative information on alloy castings, especially the chromium-nickel and straight chromium alloys manufactured by General Alloys Co. to resist corrosion and high temperatures, is contained in Bulletin D-17.

Structural Bronze

Olympic Bronze, a high copper alloy containing silicon and zinc, is suggested by Chase Brass & Copper Co. for structural and engineering purposes. A new booklet gives many interesting details about its use. Bulletin M-59.

New Furnace Control

A new and unusual instrument for controlling heating rate of electric furnaces is announced by Lindberg Steel Treating Co. An interesting folder tells how this device "turns down the heat" on any size electric furnace. Bulletin Ar-66.

Non-Ferrous Annealing

General Electric Co. describes bell-type furnaces for annealing non-ferrous metals in a new folder which gives many data on operation and performance. Description is from technical rather than sales angles. Bulletin Ar-60.

Testing with Monotron

Shore Instrument & Mfg. Co. offers a new bulletin on Monotron hardness testing machines which function quickly and accurately under all conditions of practice. Bulletin Je-33.

Localized Treating

American Gas Furnace Co. offers information on production machines for localized hardening, tempering or annealing of tools, saws, springs, screws and machine parts of all kinds, using gas as fuel. Bulletin Ag-11.

Homo Tempering

Leeds & Northrup Co. introduces a specialized Homo furnace for tempering heavy, dense loads of small particles. Production can be multiplied as much as four times. Complete description is given in Bulletin Je-46.

Quenching Handbook

E. F. Houghton & Co. have published an excellent 80-page handbook on the subject of quenching. More than 30 charts and photomicrographs help tell the story. A copy will be sent free to those who request it. Bulletin Jl-38.

Copper Welding Rods

American Brass Co. describes in complete detail the welding properties and individual characteristics of 14 different copper alloy welding rods. The 16-page booklet also makes specific recommendations of welding procedure. Bulletin Je-89.

Optics in Metallurgy

Many uses for optical instruments in metal working are described in a new booklet of Bausch & Lomb Optical Co. Photomicrography is prominent, but this well illustrated booklet shows many other interesting optical instruments. Bulletin No-35.

Roll Grinding

Carborundum Co. has published a 50-page handbook on roll grinding containing a great store of information on this subject. Carefully written and illustrated, this treatise has real practical value. Bulletin Au-57.

Thermit Welding

Metal & Thermit Corp. offers a new booklet showing all the possibilities of Thermit welding, explaining the action, and telling in detail how representative Thermit welds can best be made. Well illustrated and clearly written. Bulletin Ar-64.

Hardness Testing

Men interested in hardness testing may find it worth while to read the recent catalog of Wilson Mechanical Instrument Co. which describes the latest design of Rockwell hardness testers and auxiliary work supports. Bulletin Sp-22.

Cold Drawn Shafting

Union Drawn Steel Co. has an interesting and attractive booklet on cold finished shafting. The complete story of its manufacture is told, and recommendations for specific applications are given. Bulletin Ar-83.

Nickel Cast Iron's Uses

The role of nickel and nickel-chromium cast iron parts in such applications as fabricating sheet metal, pressing and forging is interestingly explained in a new pamphlet of International Nickel Co. Bulletin Ag-45.

Steel Specifications

A handy, up-to-date specification sheet for carbon and alloy steels is offered by Timken Steel & Tube Co. On one page are printed analyses of all important types of Timken steels. Bulletin Jy-71.

18-8 Steels

Republic Steel Corp. has prepared a new 16-page booklet giving up-to-the-minute data on Enduro 18-8 stainless steels including their several special analyses. Authentic metallurgical and fabricating information is given. Bulletin Je-8.

Controlled Steels

Carnegie Steel Co. has published a very interesting booklet which describes in some detail the process control used in the production of uniform steels. Bulletin Je-85.

High Strength Steel

Cromansil steel, a development of Electro Metallurgical Co., has high strength and good ductility "as rolled" and is thus fine for structural applications where its great strength saves much dead weight. Bulletin Je-16.

Hardening at 2500°F.

C. I. Hayes, Inc., describes their Certain Curtain electric furnace for hardening alloy and high speed steels in the range 1850-2500° F. Emphasis is laid on the features of Hayes Certain Curtain atmosphere control. Bulletin Jy-15.

Big-End-Up

Gathmann Engineering Co. briefly explains the advantages of steel cast in big-end-up ingots, showing the freedom from pipe, excessive segregation and axial porosity. An 82% ingot-to-bloom yield of sound steel is usual. Bulletin Fe-13.

Carbonol Process

The Carbonol process of carburizing is described in detail in a folder of Hevi Duty Electric Co. Results are said to be quicker, cleaner and better cases at very low cost. Bulletin Jy-44.

Sheffield Steels

Wm. Jessop & Sons, Inc., have a booklet which tells why a special anneal and a proper balancing of carbon, manganese and tungsten combine to make Sheffield Superior oil hardening steel non-distorting and easily machinable. Bulletin Jn-61.

Carburizing Boxes

Driver-Harris Co. devotes a folder to Nichrome cast carburizing boxes. Physical properties at room temperature and under operating conditions are given, as are the advantages of Nichrome castings for such service. Bulletin Jr-19.

Air for Furnaces

Users of gas or oil-fired furnaces know the necessity for a dependable source of large volumes of air at low pressures. A generously illustrated folder of Spencer Turbine Co. shows why their Turbo-Compressors give unfailing, economical air service. Bulletin Mr-70.

X-Rayed Alloy Castings

Electro Alloys Co. describes their X-Ray inspection of Thermalloy heat resisting castings for high temperature work. Considerable data on the use of X-Ray tubes and "radon" capsules to check foundry practice are presented. Bulletin Oc-32.

Heat Controller

As a companion instrument to their new indicating pyrometer, Foxboro Co. has introduced a new and inexpensive temperature controller which is dependable and easy to operate. Close control of temperatures is possible. Bulletin Mr-21.

Uses of Molybdenum

Climax Molybdenum Co. offers a useful 50-page booklet showing the benefits conferred by alloying molybdenum with iron and steel. The engineering data presented are made clear by many tables and illustrations. Bulletin Au-4.

Metallograph

Leitz Large Micro-Metallograph "MM-1". A most interesting 36-page publication containing numerous photomicrographs on the very latest developments in metallographic equipment. Special attention is invited to the arrangement for dark-field illumination by means of which detrimental reflection even in the most difficult cases is avoided. Bulletin Se-47

Blast Cleaning

A rugged blast cleaning cabinet for rapidly cleaning small work is described in a recent folder of Pangborn Corp. Full information on the operation of this machine is presented; many drawings and pictures are included. Bulletin Je-68.

Oxwelding Stainless

Linde Air Products Co. has published a handbook of instructions for successfully welding corrosion resisting steels by the oxy-acetylene process. Welding procedures and weld treatments are carefully explained. Bulletin Jy-63.

Atmosphere Furnaces

An interesting folder of Service Combustion Corp. gives performance data on their atmosphere furnaces in actual production bright annealing of ferrous and non-ferrous metals and carburizing, nitriding, forging and hardening without scale. Bulletin De-51.

New Tempering Furnace

American Electric Furnace Co. has a new, low-priced electric air tempering furnace. It heats to 600° F. in 5 min. and to 1000° F. in 15 min., transferring heat to work 50 times faster than still air and 6 times faster than salt. Bulletin Mr-2.

11 Stainless Steels

Pertinent facts on 11 different types of Bethadur and Bethalon corrosion resisting steels are presented in a 40-page Bethlehem Steel Co. booklet. Advantages and limitations of each type are frankly presented. Bulletin Fb-76.

Induction Furnaces

A publication of Ajax Electrothermic Corp. tells of the development, operation and uses of commercial Ajax-Northrup coreless induction furnaces energized by motor generator sets. Bulletin Jr-41.

Manual of Pyrometry

Brown Instrument Co. offers an elaborate manual which describes the 50 exclusive features of their potentiometer pyrometer. The book will greatly interest those who must maintain accurate temperature. Bulletin Jr-3.

Kanthal Alloys

S.K.F. Steels, Inc., offer a descriptive booklet on Kanthal alloys. Certain of these alloys may be used as resistance elements; others are for furnace parts or other heat resisting applications. Full details are given in Bulletin Je-78.

X-Rays in Industry

General Electric X-Ray Co. has available a profusely illustrated brochure which gives the complete story of the industrial applications of X-Rays, the modern inspection tool. Bulletin Ma-6.

Cast Vanadium Steel

Jerome Strauss and George L. Norris have written a technical booklet for Vanadium Corp. of America describing the properties developed by steel castings containing various percentages of vanadium. Bulletin S-27.

Pickling Inhibitors

A pamphlet describing the nature and use of Grasselli Inhibitors is offered to those interested in pickling. A feature is a table of inhibitor strengths recommended for pickling various steels. Bulletin Ap-95.

Electric Furnaces

The electric furnaces made by Hoskins Mfg. Co. are well presented in their latest catalog. Contents include data on 17 types of furnaces and some valuable information on Chromel resistance wires and thermocouples. Bulletin Sp-24.

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CHROMIUM STEELS

(Continued from page 21) class of alloy insofar as its resistance to oxidation at elevated temperatures is concerned, by the titanium addition. This is undoubtedly due to the fact that titanium combines with carbon to form stable carbide and permits more of the chromium to go into solid solution. Chromium carbides in themselves are very resistant to corrosion and high temperature oxidation, but when precipitated do not benefit the solid solution, as they impoverish it in chromium. It has been suggested by certain investigators that there is a difference in potential between the carbides and the solid solution which promotes electrolytic corrosion in mediums which will carry the current, and this has been found to be true in many instances.

An interesting experiment was conducted upon a number of alloys to bring out their relative resistance to high temperature oxidation. Specimens approximately ½ in. diameter and 1½ in. long were subjected to a temperature of 1500° F. for a period of several weeks in an electric furnace open to air at the ends. Temperature was closely controlled by an automatic regulator. Each week samples were examined, scale knocked off and loss in weight measured.

Cumulative loss in weight is plotted against time in weeks in the curves on page 20. Compare curves 8 and 3, which show the effect of titanium in improving the resistance to oxidation in the 4 to 6% chromium alloys.

In general, the 4 to 6% chromium alloys with or without molybdenum or tungsten are not recommended for service above 1100° F., as they then oxidize rather rapidly. However, if titanium is present it is believed that certain services can be recommended up to around 1400° F.

Creep values have been determined on all types of the 4 to 6% chromium alloys. It is very difficult to make comparisons, as there are so many possible errors which can be present in creep testing that it is really unfair to compare data from different sources unless the tests were all made in an identical manner, using identical equipment. It can be stated with some certainty, however, that the titanium-bearing material possesses creep strength equal to that of the steel without titanium, and it will probably be found eventually that the creep values are actually somewhat better.

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